AD-A069 625 TACTICAL AIR WARFARE CENTER EGLIN AFB FLA F/G 5/5

FOLLOW-ON SIMULATOR COMPARATIVE EVALUATION.(U)

MAY 79 D L KONOPATZKE, R S VAN ARSDALL

UNCLASSIFIED NL

1 OF 1

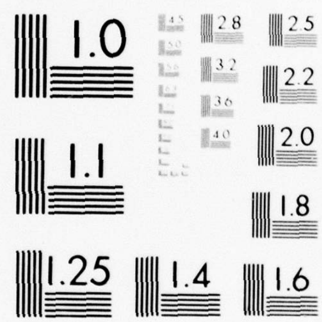
AD A069625

END

DATE FILMED

7-79

DDC



MICROCOPY RESOLUTION TEST CHART

2
B.S.

LEVEL II

Final Report

FOLLOW-ON SIMULATOR COMPARATIVE EVALUATION

See back page to 1473

MAY 1979

TACTICAL AIR COMMAND

USAF TACTICAL AIR WARFARE CENTER

EGLIN AFB, FLORIDA 32542

FOLLOW-ON
SIMULATOR COMPARATIVE EVALUATION

Final Report

May 1979

Prepared by: DANIEL L. KONOPATZKE, Maj, USAF
Surface Attack Simulators Directorate

MR. RIKER S. VAN ARSDALL
Operations Analysis

Submitted by: JOHN A. HALL, Col, USAF
DCS/Aircrew Training Devices

Approved by: GERALD J. CAREY, JR., Maj Gen, USAF
Commander

This report has been reviewed and approved by
Headquarters Tactical Air Command

TACTICAL AIR COMMAND
USAF TACTICAL AIR WARFARE CENTER
EGLIN AIR FORCE BASE, FLORIDA

FOREWORD

The United States Air Force Tactical Air Warfare Center's Deputate for Aircrew Training Devices (USAFTAWC/TN), Eglin AFB, Florida, was responsible for the planning and conduct of the follow-on simulator comparative evaluation. This project was directed by Headquarters Tactical Air Command and was conducted from 23 August to 3 October 1978.

The evaluation team consisted of the following personnel:

Daniel L. Konopatzke, Maj, USAFTAWC/TNS
George H. McKinney, Jr., Maj, 4444OPS Squadron
Frank J. Romaglia, Capt, 35th Tactical Fighter Wing
Trevor J. Horsley, CMSgt, 57th Fighter Weapons Wing
Riker S. Van Arsdall, USAFTAWC/OA

USAFTAWC wishes to express its appreciation to the following organizations and individuals for their support and cooperation in this project:

General Electric Company	Mr. Dallas Butler General Electric, Ground Service Division Daytona Beach, FL 32015
Naval Training Equipment Center AWAVS Simulator	Mr. Walter S. Chambers Naval Training Equipment Center Code N-741 Orlando, FL 32813
NASA Langley Research Center Differential Maneuvering Simulator	Mr. B. R. Ashworth NASA Langley Research Center Mail Stop 125B Hampton, VA 23665
Singer Co., Link Division DRLMS, DIG, NVA	Mr. James O'Connell Singer Simulator Products Division Sunnyvale, CA 94086
Deutsche Lufthansa Boeing 707-330C Simulator	Mr. John Bastow Redifon Simulation LTD Gatwick Road Crawley Sussex, UK
Ministry of Defense	Group Capt D. M. Richard DDTO (RAF) Room 219 Adastral House Theobolds Road London, UK WC1

	Mr. A. G. Parfitt Science 3 (RAF) Room 801A, Lacon House Theobolds Road London, UK WC1X8RY
Continental Airlines DC-10 Simulator	Mr. William Laughlin Continental Airlines 7300 World Way West T-115 Los Angeles, CA 90808
60th Military Airlift Group C-5A Simulator	Maj Alvin Machtmes 60th Mil Airlift GP Travis AFB, CA 94535
Singer Co., Link Division Binghamton, NY	Mr. Raymond J. Pawlikowski Singer Simulator Products Division Binghamton, NY 13902
Evans and Sutherland SP-1 and SP-2	Mr. Gus Liapis Evans and Sutherland Corporation 580 Arapeen Drive Salt Lake City, UT 84108
NASA Johnson Space Center Shuttle Mission Simulator	Mr. C. H. Woodling NASA JSC Mail Code FE Houston, TX 77058
AFHRL Advanced Low Cost G-cueing System	Mr. Don Gum AFHRL/ASM Wright-Patterson AFB, OH 45433
RAF Coltishall Jaguar Simulator	SQDN LDR Richard Dye RAF Coltishall NR. Norwich, UK
RAF Coningsby Radar Scope Interpretation Trainer	SQDN LDR R. J. Rodgers RAF Coningsby, OC 1 SQ Lincolnshire, UK LN44SY
Redifon Simulation LTD Scanned Laser Visual System	Mr. Adrian Tripp Redifon Simulation LTD Gatwick Road Crawley Sussex, UK
RAF Valley Hawk Simulator	SQDN LDR Alan Scott RAF Valley Holyhead, Anglesey, UK

British Aerospace Corp. Air-to-Air Combar Simulator	Mr. Arthur G. Barnes BAC, Flight Simulator Department Military Aircraft Division Warton, Lancastershire, UK

SUMMARY

The purpose of the follow-on simulator comparative evaluation was to evaluate those devices/developments that have occurred in the simulator field since the original simulator comparative evaluation report, Defense Documentation Center number ADB023450L, dated November 1977. The conclusions/recommendations reached in the current evaluation are intended to update those found in the first evaluation and to reflect state-of-the-art capabilities in simulation. A total of 16 visits were made to operational and developmental sites. Fighter pilots with F-4, F-5, A-7, and F-15 experience in the Tactical Air Command served as evaluators during this project.

Six-degree-of-freedom motion bases provided realistic cues during takeoff, instrument flight (i.e., nontactical and mild maneuvering), and landing. A controlled scientific study is required to determine the training value of cues provided by a motion system.

Properly integrated combinations of G-suits, G-seats, buffet systems, and the helmet loader provide useful cues during performance of tactical tasks. Current systems possess the physical characteristic necessary to provide such cues; however, a combination of all such devices must be integrated and optimized on an operational trainer.

Computer-generated image technology has advanced to the point where adequate daylight visual scenes can be provided to train takeoff and landing tasks. In addition, the capability exists to provide limited training in some tactical tasks. Major problem areas are the poor resolution and insufficient scene content and detail.

Altitude and ground translation cues are required to effectively train both air-to-air and air-to-surface combat tasks.

Two very useful instructional features were observed: the ability to conduct independent training at different crew stations in multiplace simulators and the automatic performance measurement capability of the British Aircraft Corporation air combat trainer.

Pseudo-instruments displayed on instructor operator station cathode ray tubes are superior to alphanumeric readouts of aircraft performance and may be used to replace repeater instruments on instructor consoles.

The digital radar land mass system provides nearly perfect depictions of surface radar returns; however, care must be taken to insure that the clarity of this system does not exceed that of actual aircraft radar systems.

CONTENTS

ILLUSTRATIONS

TERMS AND ABBREVIATIONS

A/A. . . . . .air-to-air
AC . . . . .aircraft commander
ACS. . . . . .air combat simulator
AFB. . . . . .air force base
A/S. . . . . .air-to-surface
BAC. . . . . .British Aerospace Corporation
bpi. . . . . .bit per inch
CGI. . . . . .computer-generated imagery
CPU. . . . . .central processing unit
CRT. . . . . .cathode ray tube
DEC. . . . . .Digital Equipment Corporation
DIG. . . . . .digital image generation
DMS. . . . . .differential maneuvering simulator
DOF. . . . . .degree(s) of freedom
DRLMS. . . . . .digital radar land mass system
edge . . . . .A scene display line that separates two color shades on a plane or defines the intersection of two or more planes.
fidelity . . . . .the degree to which the simulator simulates the aircraft and its systems.
FLOLS. . . . . .Fresnel lens optical landing system
FOV. . . . . .field of view
G-force. . . . . .gravity
HLD. . . . . .helmet loader device
IBM. . . . . .International Business Machines
IOS. . . . . .instructor operator station
IP . . . . .instructor pilot
K. . . . . .thousand
MOS. . . . . .metal oxide semi-conductor
NASA . . . . .National Aeronautics and Space Administration
NM . . . . .nautical miles
Novoview . . . . .night/dusk/dawn CGI visual system; an Evans and Sutherland trade name.
NVS. . . . . .night visual system
pixel. . . . . .picture element - smallest resolvable element on a CRT display
RAF. . . . . .Royal Air Force
R&D. . . . . .research and development
RAM. . . . . .random access memory
resolution . . . . .ability to discern detail on a visual display; measured in arc-minutes.
SEL. . . . . .Systems Engineering Laboratories
SMS. . . . . .shuttle mission simulator
SP-1, 2. . . . . .Special Performance 1, 2 (Evans and Sutherland visual systems).
TAC. . . . . .Tactical Air Command
TAF. . . . . .tactical air force

tuberosity blocks. . . . . . .raised or protruding surface
TV . . . . .television
UK . . . . .United Kingdom
US . . . . .United States
USAFTAWC/TN. . . . . .USAF Tactical Air Warfare Center/Aircrew Training Devices Deputate
USN. . . . . .United States Navy
WSO. . . . . .weapon system operator

FINAL REPORT

FOLLOW-ON SIMULATOR COMPARATIVE EVALUATION

1. INTRODUCTION.

a. In April 1976, the Commander, Tactical Air Command (TAC) directed the United States Air Force Tactical Air Warfare Center (USAFTAWC) to evaluate the simulator systems available to the United States Government, allied air forces and airlines, and those under development by industry. This broad assessment of simulator systems and subsystems, which represented the state of the art in aircraft simulation, was conducted to provide TAC with the following:

(1) An extensive listing of current devices and associated instructional features.

(2) A detailed description of the capabilities and limitations of each system/subsystem.

(3) A subjective assessment of the existing and/or potential ability of each system or subsystem to satisfy tactical air-to-air (A/A) and air-to-surface (A/S) training requirements.

(4) Empirical data that will serve as an important part of the basis for a determination of the simulator motion platform requirement.

b. The evaluation of 35 training devices in the USAF, US Navy, US Marine Corps, Royal Air Force (RAF), industry, and the airlines was conducted in late 1976 and early 1977. The final report, entitled Simulator Comparative Evaluation, Defense Documentation Center Number ADB 023450L, was published and distributed in November 1977. Conclusions and recommendations pertaining to tactical aircraft simulators included the following.

(1) An effective visual system, enhanced by optimized G-seat, G-suit, buffet systems, and acceleration/deceleration cues, would provide adequate motion cues for the performance of the A/A and A/S tasks; further, these are required features for future fighter simulators.

(2) Computer-generated image (CGI) systems afforded the clarity and resolution necessary to recognize and identify objects at normal slant ranges.

(3) Normal techniques and procedures could be employed only in simulators that duplicated the field of view (FOV) of the aircraft.

(4) An interactive two-versus-one capability was considered the most important requirement in future A/A simulation training.

2. PURPOSE OF THE EVALUATION. The initial evaluation report indicated that periodic follow-on evaluations would be conducted with emphasis on the ability of current or developmental subsystems to satisfy tactical A/A and A/S training requirements. This evaluation, conducted in August-October 1978, was the first follow-on visit.

3. METHOD OF ACCOMPLISHMENT.

a. In preparation for the evaluation, USAFTAWC/TN personnel screened the initial report to determine significant design changes. The design changes that were of interest to TAC were placed on a list of potential candidates. In addition, systems that were originally selected as candidates in 1976 but could not be scheduled for evaluation were listed. Lastly, major manufacturers of aircraft simulators were contacted to identify any current developmental subsystems of potential benefit to TAC.

b. Final selection of the devices and developmental subsystems to be evaluated was made based upon availability during the proposed visitation period. This final list included six military devices (two USAF, one US Navy, and three RAF), two National Aeronautics and Space Administration (NASA) devices, two airline devices (one US and one German), and six devices from industry (four US and two United Kingdom (UK)).

c. The evaluation team, consisting of three TAC fighter pilots as evaluators, one operations research analyst, and an Air Force simulator technician, was selected during the planning stage for the evaluation. One of the pilots and the analyst had been members of the original evaluation team. The team devised a checklist to be used by each evaluator at each site visited. The main approach was to determine whether the device/subsystem possessed any features of potential use in tactical fighter simulation. Where possible, planning included a hands-on evaluation by each pilot. When the evaluation was to be performed by observing a demonstration only, appropriate questions were included in the checklist to insure that all salient features were addressed. Main items on the checklist were: visual system feature/cues, motion platform, G-suit, G-seat, sound cues, physiological effects, instructor operator station (IOS), potential negative training risk, and overall training value. Only the checklist items appropriate to the device being evaluated were introduced during each evaluation. The basic responsibilities of team members were as follows.

(1) Evaluation Pilots. The evaluation pilots were responsible for an individual subjective evaluation of each device.

(2) Operations Research Analyst. The analyst was responsible for insuring that all appropriate items from the checklist were investigated during the evaluation. The analyst conducted the group debriefing after the evaluation of each device and reconciled any marked differences through group discussion.

(3) Simulator Technician. The simulator technician was responsible for developing a complete, detailed technical description of the system or subsystem assessed during the evaluation.

4. RESULTS AND DISCUSSION. The information presented in this paragraph is based upon the subjective appraisal of the three evaluation pilots. Because of the wide diversity in nature of the facilities/devices visited on this evaluation, there is no obvious format for discussion. Therefore each location visited will be discussed individually, with those features directly applicable to tactical simulation receiving the most emphasis. A brief description of each device precedes the evaluation discussion. Detailed technical descriptions and specifications are presented in Annex A, Appendices 1-11.

a. Continental Air Lines DC-10, Los Angeles, California. The DC-10 simulator has a six-degree-of-freedom (DOF) motion base and a two-window night visual system. The cockpit is a duplicate of the aircraft with positions for the pilot, co-pilot, flight engineer, and observer plus an IOS. (For complete description see Annex A, Appendix 1.)

(1) The simulator exhibited sufficient fidelity to train the night straight-in landing task. The motion system provided excellent cues for buffet, acceleration/deceleration, roll, pitch, and yaw. Landing cues were especially good from touchdown through rollout, even to the detail of feeling the "thump" of the nosewheel tire on the runway centerline lights.

(2) The motion cues were well coordinated with outside references provided by a basic Singer night visual system (NVS). The various airport scenes were quite good with obvious attention to detail in the placement of light strings and red-lighted radio towers. The scene was unrealistically clear because it lacked normal atmospheric diffusion of light. Also, all light points were of similar size and intensity and did not vary as a function of range. Weather simulation was good for fog/reduced visibility, but clouds were unrealistic because there were no ragged features either on the top or bottom of the cloud deck.

(3) The IOS is located in the cockpit allowing the instructor pilot (IP) to directly monitor all aircrew activity. Desirable IOS features include the ability to conduct training in the pilot and co-pilot area separate from the flight engineer station, and a hand-held control box through which the IP can change such conditions as aircraft location, weather, and malfunction status while occupying one of the crew stations. Another useful feature is the color cathode ray tube (CRT) used to display schematics of aircraft systems. These schematics present a visual representation of malfunctions as they occur and show exactly what happens when the crew member takes appropriate

action. This graphic portrayal of system malfunctions and effects of aircrew actions was considered to be an excellent educational tool.

b. Military Airlift Command C-5A, Travis AFB, California. The C-5A simulator has a four-DOF motion base and a night CGI visual system. The Evans and Sutherland special performance 1 (SP-1) visual system provides a night/dusk presentation viewed through five windows. An instructor pilot (IP) instructs from a station inside the cockpit, whereas a technician occupies the operator's console in the computer room. (For a complete description see Annex A, Appendix 2.)

(1) The motion system in the C-5 was considered inferior to the six-DOF systems used in most airline simulators. Occasional thumping in the system detracted from training effectiveness. There were few if any acceleration/deceleration cues and no yawing sensations at all. Landing and rollout cues were present but were much too faint to be realistic.

(2) The night display was realistic with flashing radio tower lights, rotating beacon, and stars above an overcast. The bright horizon glow provided a dusk environment that assisted in visual flying. One problem with depth perception was the similarity in size of all the light points; that is, the distant lights were of the same size and brightness as the near lights. Phosphor persistence of both the approach lights and visual approach slope indicator lights was excessive, especially during rapid changes in bank and pitch. The addition of two side windows on the pilot's side and one side window on the co-pilot's side aided in maneuvering, especially during circling approaches. Unfortunately the gap between the CRTs required a different scan pattern than that used in the aircraft; this resulted in the development of flying techniques unique to the simulator.

(3) The ability to train the A/A refueling task was hampered by obvious visual defects in the KC-135 model. Most apparent was the lack of occultation of the tanker lights. The director lights were unusually large and appeared to float inside the tanker; the lights could be seen from the top and the side as well as from the bottom. Likewise, both wing-tip lights were visible when the tanker was viewed from any angle. The model was obviously composed of straight lines and lacked curved surface shading; this resulted in an angular aircraft with pentagonal-shaped engine nacelles. The gray coloration of the tanker tended to disappear into the dusk horizon when the receiver got too high. This was distracting and a source of confusion during a critical point in refueling training. The limited vertical FOV made it impossible to see the tanker from the contact position. Changing the seat position did not help since the problem was a CRT window restriction. Basic aircraft maneuvering behind the tanker was satisfactory, but the numerous visual distractions limited the usefulness of the simulator as an air refueling trainer.

c. Singer Company, Link Division, Sunnyvale, California. The evaluation team observed several research and development (R&D) demonstrations prepared by the Advanced Products Organization at Singer. The presentations were viewed on isolated devices and not on operational simulators; this made it difficult to evaluate their potential training utility. They did provide an insight to near-term, state-of-the-art simulator developments. (For a complete description see Annex A, Appendix 3.)

(1) The digital image generation (DIG) demonstration consisted of a number of moving air and ground targets maneuvered in various environments by use of a "joy stick." Effective use of curved surface shading significantly enhanced the realism of the KC-135 and MIG-21 models (see Figure 1). The scene was degraded by tanker formation lights, which maintained a relative brightness level against the background. Further degradation was caused by frequent low-level flashing of some scene details; Singer explained this as a data base problem. Accurate range estimation of the tanker was good during daylight but poor during dawn, dusk, and darkness because of unnaturally large position lights. As the aircraft moved farther away, the lights diminished in size until they reached the size of a single pixel. The lights then remained constant in size and moved in relation to one another as they changed from one raster scan to another with a small movement. Terrain modeling problems were also demonstrated along with their solutions (e.g., the use of texturing, shadows, shading, and vertical development to significantly enhance depth perception). The capability to provide numerous real-time targets with friendly/enemy fire was impressive and has definite tactical applications.

(2) The NVS was sufficient for the performance of takeoff, approach, and landing tasks and may have some training value for certain tactical tasks. Particularly applicable was the night bombing range with run-in lines, bomb circle, and weapon impact simulation. This system includes grouping of light points to simulate airborne flares and ballistically correct tracers. The F-5 model did not have sufficient fidelity for close formation practice. Training utility would be limited to the terminal phase of a night intercept.

(3) The digital radar land mass system presentation showed a simulation of a radar significant area compared to a picture of the same area taken from the aircraft's radar. The simulation was excellent with very little to differentiate between the two pictures. If anything, the simulation appeared to have greater contrast than the actual aircraft radar picture (see Figures 2 and 3).

d. Evans and Sutherland, Salt Lake City, Utah. Evans and Sutherland provided a side by side comparison of their SP-1 and SP-2 visual systems. Both systems were viewed on isolated CRTs so there was no opportunity to

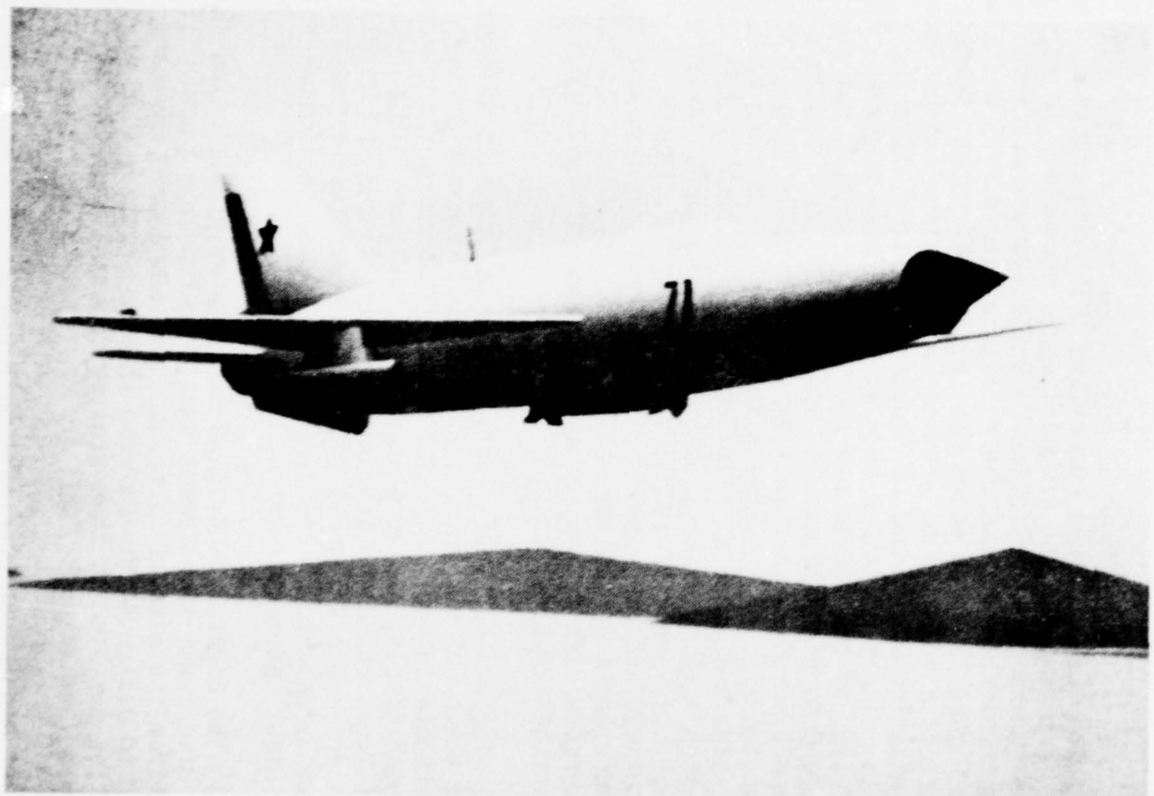


Figure 1. Singer MIG-21, CGI Model.

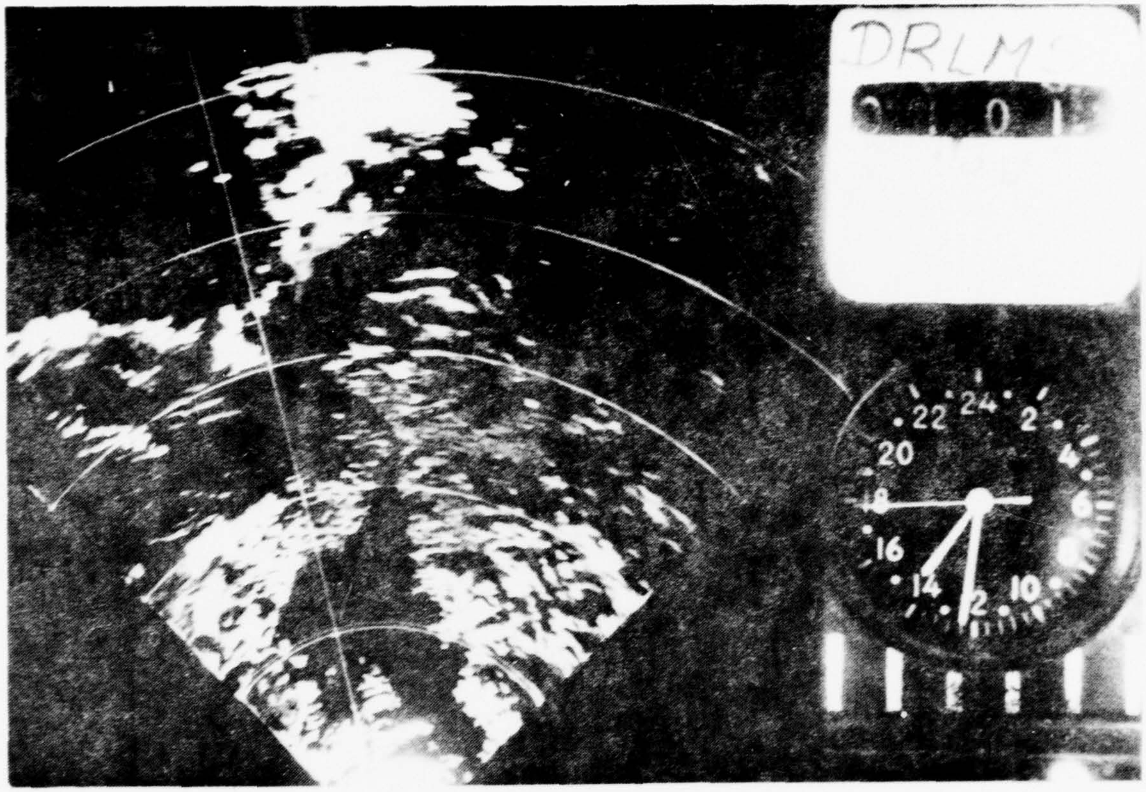


Figure 2. Digital Radar Land Mass System, Las Vegas, Nevada.

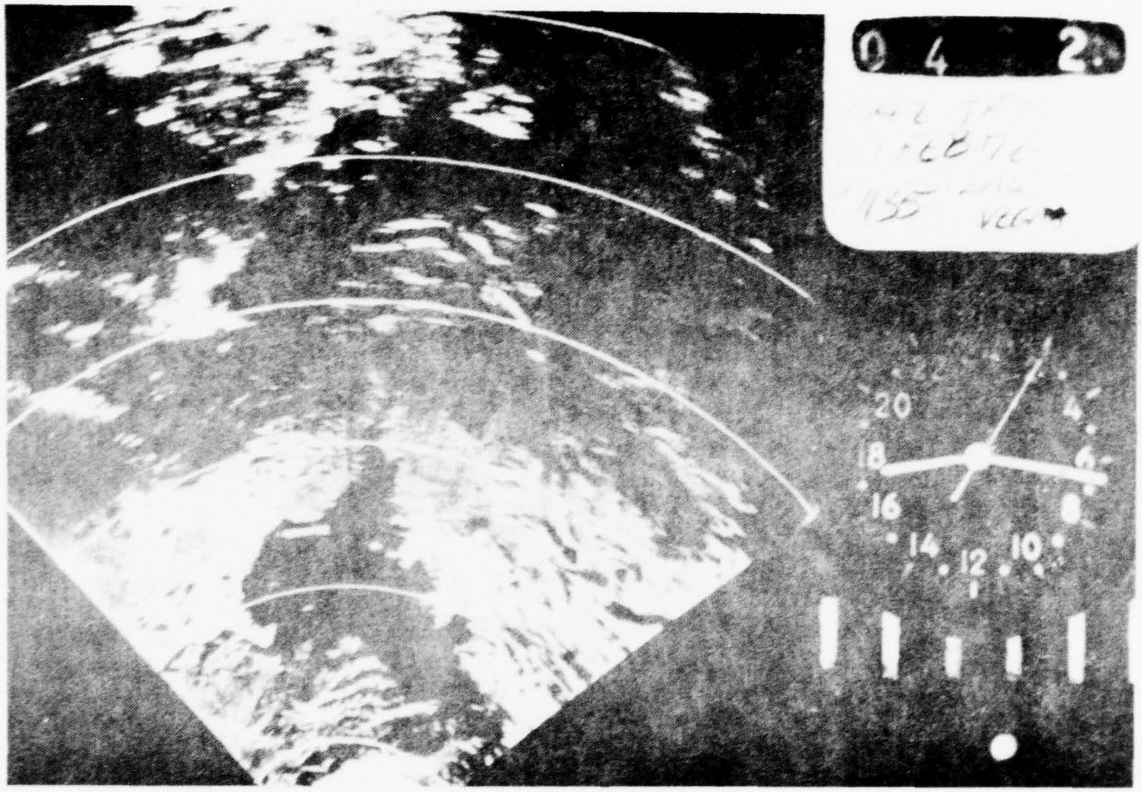


Figure 3. Aircraft Radar, Las Vegas, Nevada.

compare them in an actual simulator. The SP-2 was still in breadboard form; this resulted in a slightly degraded performance compared to the projected production model. (For a complete description see Annex A, Appendix 4.)

(1) The SP-1 is a NVS with the capability to display a KC-135 model in dusk light conditions. The night scene showed excellent attention to detail with unique use of curved light strings (e.g., a Holiday Inn sign and McDonald's arches just off final approach to one of the runways). Depth perception was provided by dimming and decreasing the size of distant lights. Weather depiction was good, although entering and leaving a low overcast was done very abruptly with little or no in-and-out effect. Landing light depiction was exceptional with three selectable lights that moved sideways when the aircraft yawed. The aircraft models were not very realistic. The KC-135 tanker did not have the detail to provide proper cues for A/A refueling training.

(2) The SP-2 is a medium intensity day visual system with a dusk/night capability. The addition of blue color allows the full spectrum in surface light depiction and sky and earth shading, and it is especially valuable in the generation of atmospheric conditions. Simulations of day and dusk scenes with fog and haze were the most realistic viewed by the evaluation team. Airport detail was sufficient for approach and landing, but overall resolution was considered marginal for surface attack and inadequate for A/A scenarios. Looking for the detail to accomplish these tasks in the somewhat dim visual scene resulted in moderate eye strain for two of three evaluation pilots.

e. NASA, Johnson Space Center, Houston, Texas. The shuttle mission simulator has a small cockpit containing pilot, co-pilot, and observer positions supported on a six-DOF motion base. Both CGI and model board television (TV) camera scenes of the approach and landing phase were observed along with a part-task trainer scene of the cargo compartment. (For a complete description see Annex A, Appendix 5.)

(1) The CGI was marginally adequate for the landing task and did not have the fidelity for surface attack or A/A target recognition. There was inadequate detail in both quality and quantity to accomplish tactical tasks. The horizon, stars, and moon were realistic, but no adverse weather conditions were observed. The flickering or scintillation of ground and air targets at high brightness levels could prove to be distracting on prolonged flights.

(2) The model board/TV probe visual scene was viewed for only 5 minutes because of focusing problems with the TV camera. The scene presented was difficult to interpret because of poor focus and low light level. The model itself appeared to have enough detail but this was lost in transmission or display.

(3) The cargo compartment part-task trainer used a CGI representation of the shuttle cargo compartment and manipulator arm. The visual scene provided the limited content required in a space environment. The only detail required was in the compartment, arm, and payload with the background filled in as black space. The scene was viewed on a number of CRTs as it would be in real life with the option of selecting different cameras for different views. The trainer was used to practice operation of the manipulator arm in loading and unloading the shuttle cargo compartment. Although an effective trainer, it does not appear to have any tactical application.

f. Air Force Human Resources Laboratory, Wright-Patterson, AFB, Ohio. The G-suit/G-seat examined at the Human Resources Laboratory were R&D items and not available in an integrated flight trainer. Therefore the pilot observations were limited to the specific device with no way of determining whether the device could be coordinated with flight maneuvers. (For complete description see Annex A, Appendix 6).

(1) G-force application and reduction on the G-suit were controlled from a computer keyboard. The G-suit inflated quickly and to the extent necessary for actual aircraft simulation. It did not appear to deflate rapidly enough. This perception may have been fostered by the evaluation pilots' inability to ascertain the timing and rate of G-force reduction.

(2) The G-seat was evaluated in a basic T-38 cockpit with no other indications of aircraft performance available. The G-force cueing was of sufficient amplitude and frequency to effectively simulate the sensation of turning, acceleration, deceleration, aircraft buffet, and positive G-force application. Roll cues were especially realistic with the ability of the seat plate to provide pressure on only one side of the posterior. Because the firmness bladder overlaying the seat pan did not retain its square shape when inflated, it gave the pilots the impression they were sitting on a rounded surface instead of on an ejection seat. The radial wings in the lower corners of the back plane provided valid cues, but the intensity depended on how much of the pilot's back they contacted and would vary with the width of the pilot's back.

g. General Electric, Daytona Beach, Florida. The demonstration at General Electric was a presentation of R&D features for the enhancement of the CGI. Through non-real time, the visual scenes could provide the cues necessary for training the full spectrum of A/A and A/S tasks. Of particular interest was the conservation of edges by the use of a circle generator. The quarter circle segments provided circular features for clouds, trees, wheels, and other curved surfaces, with no cost in edge capacity. Curved surface shading, texturing, and variable see-through shadowing added realism to the scene, anchored objects to the surface, and provided depth perception required for low-level flight. The blended level of detail also added realism, especially when an object of interest

was approached. With blending, the object would transition into ever-increasing detail rather than jump into view when a certain distance parameter was met.

h. Aviation Wide Angle Visual System, Naval Training Equipment Center, Orlando, Florida. This simulator is a single cockpit configuration of the Navy T-2 Buckeye with a dome visual system, a six-DOF motion system, and a G-suit/G-seat. It is used as an R&D vehicle and a test bed to train Navy pilots in the carrier landing task. (For a complete description see Annex A, Appendix 7.)

(1) The motion system provided realistic cues with minor degradation of performance during abrupt maneuvers. Stalls, turns, diving, and climbing were excellent, but there was little sensation of yaw. Excellent realism was attained in the catapult launch and trap recovery on the carrier. The G-suit was not available for evaluation, but the G-seat did provide good aircraft performance indications, especially in stall buffet. It was felt that the system had the capability to provide realistic aircraft feel with a G-seat/G-suit, six-DOF motion system, and a CGI/model visual system once they were all working and integrated.

(2) The visual system was, for all practical purposes, inoperative for this evaluation. A suspected computer software problem precluded the use of the normal aircraft carrier model, and the CGI model was not ready for real-time operation. The scene presented was a relatively dark night over water with no moon or stars. Wave structure was noted in the landing light beam when the altitude above the water was less than 300 feet, but depth perception was difficult. A non-real-time CGI model of the carrier was projected on the dome, but approaches could not be flown. The model was used, however, to display the capability of the CGI system to provide high- and low-resolution scenes with accompanying changes in FOV. The low-resolution scene provided a good FOV (160° by 80°) but at the cost of detail. The high-resolution scene of the aircraft carrier model was much improved in fidelity but with the tradeoff to a smaller FOV (60° by 40°). The US Navy considers this a good tradeoff, since the carrier is the only object required in the scene and a wide FOV is not necessary. Another interesting demonstration was the use of the high-resolution model and a ten-to-one zoom lens on the projector. This feature permitted the pilot to view the carrier from an extended distance and then appear to fly to the carrier when the lens was zoomed for a closeup. The detail was excellent throughout the simulated approach and much more realistic than either the high or low resolution scene by itself.

(3) The pseudo-generic gauges displayed on the IOS CRT were suitable for ascertaining what was occurring in the cockpit. They are a vast improvement over alphanumeric readouts.

i. Differential Maneuvering Simulator (DMS), NASA Research Center, Langley AFB, Virginia. The DMS is a fixed-base simulator with a dome

visual system, G-seat/G-suit, and a helmet loader. Two separate cockpits are integrated through a computer to provide research in air combat. The simulators have generic cockpits and can be programmed to simulate the flight capabilities of any modern fighter aircraft. (For a complete description see Annex A, Appendix 8.)

(1) The DMS has the capability to provide high altitude, one-versus-one, basic fighter maneuvers and air combat maneuvers training. Major shortcomings are the lack of ground and altitude translation cues and lack of a fully interactive three-ship (or more) engagement capability. Target fidelity was sufficient to judge distances, aspect angles, and closure rates of a T-38 size target to a range of 9,000 feet. Targets were too bright against the sky/earth background; this made target acquisition artificially easy. The G-suit/G-seat and visual scene dimming provided excellent indications of aircraft performance. It is felt that a buffet system is required to provide meaningful cues in the high angle-of-attack flight regime. Lack of enemy ordnance launch indications hampered timely initiation of proper evasive maneuvers. The fact that any missile launched within parameters resulted in a kill was detrimental to training because the pilots could not ascertain the effectiveness of evasive maneuvers.

(2) The helmet loader complements the G-seat/G-suit and the visual system to provide highly realistic "G" sensation. The cues blend together to provide a perfectly natural G-reference. The restrictions imposed by the helmet loader accurately simulates the difficulty of visual tracking in a high-G environment. Head movement is not unnaturally restricted and the attaching strings proved easy to replace when required.

j. <u>Singer-Link, Binghamton, New York</u>. There was no hardware available for review, but several informative briefings were given by Singer personnel. The first presentation was on simulator fidelity and the degree to which operating skills can be developed in a training environment and transferred to the operating environment. This briefing included an excellent analysis of a pilot's learning curve and the kinds of cues required by the pilot at various points along the curve. A review of the physiology of motion sensing helped explain why proper onset cues are so important. A follow-on briefing identified areas of simulation that require data that are either not obtained or have been obtained but discarded. A primary example is the aeronautical data obtained during aircraft flight testing that have been disposed of before the simulator was built. Likewise, many areas of flight, such as the last 300 feet before landing, have not been examined in the depth required for adequate reproduction in the simulator. The suggestion was offered that data required for the simulator be identified at the outset so that they can be obtained at the same time that aircraft flight data are derived. A successful example of this approach is the United Airlines 727 at Denver, Colorado, which is rapidly approaching full certification by the Federal Aviation Administration for all training to include landing. The use of the simulator obviously results in a great saving of aircraft and instructor time.

k. Deutsche Lufthansa 707, Frankfurt, Germany. This simulator is a standard 707 cockpit on a six-DOF motion base with a ceiling suspension system as well as a floor base. Positions are provided in the cockpit for a pilot, a co-pilot, a flight engineer, and the instructor, who has a console directly behind the pilot. The visual system is full-color, daylight with the CGI viewed through two 30- by 44-inch windows. (For a complete description see Annex A, Appendix 9.)

(1) The motion system was capable of providing all maneuvering cues required in the normal airline flying environment. Particularly impressive were the on-runway and immediately after takeoff cues.

(2) The Redifon full daylight CGI visual system was impressive with its great attention to detail (see Figure 4). Terrain features around the airport had sufficient detail for the approach and landing, but the scene did not provide adequate cues for low-altitude flying. The hillsides and fields away from the airport did not have the texture or relief necessary to maintain ground clearance by visual reference. These areas were enhanced by color shading and variation to denote different water depths and types of fields, but this did not aid in depth perception. A good feature, not seen before, was the fading in color and detail with an increase in distance. This added to the total realism by softening the cultural features and also assisted in range determination. The night scenes were not as good as a night-only system, because the colored light points were too large in size and they appeared to float on the surface. There were not enough lights, and those available were not arranged very realistically. The moving vehicle (a truck crossing the runway) could have tactical use as a target and demonstrated the versatility of the CGI systems. The truck driving on the runway required the pilot to make a real-time decision to go around based on an input more natural than if directed to do so by the instructor. The system demonstrated the brightness and resolution required for training some tactical tasks (e.g., conventional gunnery) and offered a preview of what can be expected in future developments.

(3) Excellent aural cues for engine noise, tire noise on the runway, spoiler, flap, gear movements, and windshield wiper slap significantly enhanced simulator fidelity.

l. Jaguar, RAF, Coltishall, United Kingdom. The Jaguar simulator has a single cockpit mounted on a three-DOF motion base. The visual system is a one window, color TV presentation of one of three terrain model boards. The simulator had been evaluated on the initial simulator comparative evaluation and was revisited to allow the two new team members an opportunity to fly it and to provide an update of its capabilities.

(1) The motion system was satisfactory during instrument flight, but would initially lag instrument and visual scene response

Figure 4. Redifon Daynite Scene, CT-4.

during rapid roll maneuvers, and then overshoot at the termination of the roll. There was insufficient buffet or other indication at high angle of attack to alert the pilot when he approached the edge of the flight envelope. This required excessive attention when maneuvering at low airspeed and/or high angles of attack to prevent loss of aircraft control.

(2) The visual scene was good for normal contact flying but was almost unusable when taxiing or landing because of blurred scene presentation below 200 feet. Tactical tasks were possible on the large scale model board but were restricted to straight-ahead maneuvers because of a lack of side windows. When transitioning between model boards, the visual presentation would blank and then give the appearance of a steep climb before going to the next board. This was disconcerting and required undue pilot attention to aircraft position on the model board to avoid the problem. The visual system was excellent as a background for contact flying and instrument approaches to the missed approach point. The model boards themselves were quite detailed and were kept up to date with modifications to reflect real-world changes.

m. Radar Scope Interpretation Trainer, RAF Coningsby, United Kingdom. This radar part-task trainer is designed to aid the F-4 weapon system operator (WSO) and aircraft commander (AC) in learning proper intercept geometry. It was initially procured by the US Naval Training Equipment Center in Orlando, Florida. Developed in 1967, the hardware, student, and instructor stations are somewhat outmoded.

(1) The device consists of a console occupied by the AC and WSO who sit side by side, several feet apart. The rudimentary console on the AC's side contains several basic flight instruments as well as the necessary switches to launch missiles. The WSO station is more complete and contains the entire radar set. The screen displaying the intercept geometry is in front of the console and across the room; it can be shielded from or visible to the student aircrew. The display shows an intercept geometry from above: The interceptor is in the middle of the screen with the radar beam projected on the screen. The other aircraft is displayed in the correct geographic location in relation to the intercept geometry.

(2) It was considered an outstanding training device because the student, while running the intercept on the radar scope, could look up and correlate a moving blip on the radar screen with the correct physical location of the target aircraft. This allowed the student to draw a mental picture of what was occurring during an interception, rather than having to rely on memorized formulae.

n. Redifon Simulation Limited, Crawley, United Kingdom. The complete simulators available at Redifon were of standard airline configuration

with no tactically significant features. There were several devices in the pre-production or pre-acceptance category, howev-, that do have application in tactical simulation. (For a complete description see Annex A, Appendix 10.)

(1) The control loading research vehicle was quite impressive with its capability to quickly and accurately duplicate aircraft feel. The low-friction actuators and easily adjusted rheostats made it possible to fine tune the flight controls for every conceivable combination of air load and hydraulic flight control feedback.

(2) Although not fully operational, the scanned laser visual system provided the most detailed visual scene to date. The scene was projected in non-real time and, though hampered by distortion in the form of vertical bars and a low-light level, had sufficient detail to permit differentiation between individual branches on trees. Some of this detail could be attributed to the unusually large model board used, but the picture was still a definite improvement over the standard TV/model board system.

(3) The B-52 part-task air refueling trainer provided enough detail and realism to accomplish the air refueling task. The model showed great attention to detail including formation lights, oil streaks on the fuselage, and exceptionally realistic director lights. The realism was enhanced by refueling instructions from the boom operator, which were clear and correct although somewhat clipped. The visual scene was distorted at the outer edge; this gave the tanker "bent wings," but this anomaly was being corrected.

o. Hawk, RAF Valley, United Kingdom. The Hawk is a basic emergency procedures/instrument flight trainer with a three-DOF motion base. Although it does not have a visual system, it is designed for easy retrofit should one be desired. The entire simulator is contained in three truck-transportable modules for ease in relocation. (For a complete description see Annex A, Appendix 11.)

(1) The motion system was adequate for instrument flight but did not provide all the cues desired for aerobatic flight. The flight dynamics of the simulator appeared realistic to the evaluators and various RAF IPs and students.

(2) The instructor console is very simple but effective. By means of an alphanumeric keyboard, two CRTs, and two flight instrument repeaters, the instructor is able to monitor the student's performance and provide all necessary inputs. The alphanumeric portrayal of all instruments except the horizontal situation indicator and course deviation indicator is awkward and difficult to

read quickly. Emergency procedures can be pre-programmed or inserted during the flight by CRT page selection and event designation. A listing of upcoming events is available by selecting the appropriate page. An in-house modification provides a graphic portrayal of precision instrument approaches through the normal computer hard copy printer. A record/playback feature is also available to record the flight performance during an approach for a hands-off playback demonstration for the student.

(3) Although the Hawk simulator is a simple device with no visual system and a limited motion base, the compactness and simplicity will be definite assets in remote areas or mobile sites.

p. British Aerospace Corporation Air-To-Air Combat Simulator (ACS), Warton, United Kingdom. The ACS is a single cockpit R&D device used to study A/A combat. It has a fixed base with a seat buffet system and a dome visual system. It can be programmed to simulate the flight dynamics of any modern aircraft.

(1) The limited excursion seat buffet system provided excellent high angle-of-attack cues. This system, along with the visual scene, provided sufficient motion cues to train medium- and high-altitude one-versus-one air combat maneuvers and basic fighter maneuvers tasks.

(2) The dome visual system gave sufficient cues to determine range and approximate aspect angle of a Flogger-size target to a range of 1.5 miles. Beyond this range, the target became a point of light; this made it impossible to determine aspect angle or closing velocity. Training was severely degraded by lack of a visual scene in the rear hemisphere. Depiction of the opponent's position and altitude on an in-cockpit CRT made it artifically easy to maneuver against a bogey in the rear hemisphere. Lack of altitude cues precluded accomplishment of low-altitude air combat training. The target remained bright when the rest of the visual scene darkened under high G-force conditions. This was unrealistic and made target acquisition too easy.

(3) The most impressive feature of this ACS was the automatic performance measurement capability. The availability of an instant, hard-copy printout made it possible to objectively measure aircrew performance against a pre-programmed adversary and to provide constructive feedback after each engagement. Any one of 60 parameters can be recorded and then reviewed with the student as the mission is being replayed on a remote CRT. The increase of adversary capabilities by increments could provide a challenging training scenario for pilots of varying skill and experience levels. Cockpit indication of being in parameters for launch is also an excellent instructional feature. A hard-copy printout showing the exact time periods the aircraft is in firing parameters, coupled with the time of release, is also excellent.

5. CONCLUSIONS. Annex A, along with the page and paragraph references provided below, contain supporting data for each conclusion.

a. A properly integrated six-DOF motion base can provide useful cues for buffet, acceleration/deceleration, roll, pitch, and yaw during the relatively mild maneuvering encountered in instrument flight and landing (pages 3, 11, 13, paragraphs 4a(1), 4h(1), 4k(1)), respectively).

b. State-of-the-art G-seats/G-suits have the physical capability to provide realistic cues for turning, acceleration/deceleration, buffet, and positive G-force application (pages 10, 11, paragraphs 4f(1)(2), 4h(1)), respectively.

c. The DMS helmet loader provides extremely useful and realistic G-force cues (page 12, paragraph 4i(2)).

d. Limited FOV night visual systems are adequate for teaching the straight-in landing task under various conditions of ceiling and visibility (pages 5, 9, paragraphs 4c(2) and 4i(2)), respectively.

e. Although significant technological advances have been made, current CGI systems do not provide all the cues required for training A/A and A/S tasks (page 9, paragraph 4i(2)).

f. The SP-2 day visual system displayed the most realistic fog and haze visibility restrictions (page 9, paragraph 4d(2)).

g. The fading of color and detail as a function of range assisted greatly in slant range determination (page 13, paragraph 4k(2)).

h. The KC-135 camera model used in the B-52 part-task trainer provides the fine detail required for the air refueling task. CGI KC-135 models did not provide sufficient cues to train the air refueling task (pages 4, 16, paragraphs 4b(3) and 4n(3)), respectively.

i. The capability to conduct independent training at different crew stations in multiplace simulators enhances the training effectiveness of such devices (page 3, paragraph 4a(3)).

j. Pseudo instruments displayed on IOS CRTs provide sufficient indications of aircraft performance (page 11, paragraph 4h(3)).

k. Altitude and ground translation cues are required to train the full spectrum of air combat tasks (pages 12, 13, 17, paragraphs 4i(1), 4k(2), and 4p(2)), respectively.

l. The automatic performance measurement capability of the British Aerospace Corporation ACS is a valuable instructional tool (page 17, paragraph 4p(3)).

m. Realistic radar simulation is provided by the digital radar land mass system (page 5, paragraph 4c(3)).

n. Not enough emphasis is placed on obtaining/retaining accurate aeronautical data for programming flight characteristics in simulators (page 12, paragraph 4j).

6. RECOMMENDATIONS: The following recommendations pertain to the applicability to future tactical air force simulators of the systems/devices evaluated. These recommendations update the findings of the initial Simulator Comparative Evaluation Final Report, Defense Documentation Center number ADB-023450L, November 1977. Copies can be ordered by calling AUTOVON 284-7633. It is assumed that all of the features recommended can be integrated into a single weapon system trainer and provide the capability equal to or better than that demonstrated as an R&D device.

a. Objective performance measurement criteria should be determined and used to evaluate the contribution of motion cues to train instrument flight and landing tasks.

b. Future multiplace simulators should provide the capability to conduct independent training at the different crew stations.

c. Pseudo instruments displayed on CRTs should be used at an IOS in lieu of alphanumeric readouts.

d. ACS must include ground and altitude translation cues, which allow a pilot to determine relative altitude and position.

e. Further evaluation of the helmet loader should be accomplished to determine whether the additional G cues provided by this device warrants procurement.

f. Guidelines should be established for obtaining the aeronautical data required to accurately simulate flight dynamics.

g. Automated performance measurement systems with capabilities similar to those in the PAC ACS should be included in future weapon system trainer sets.

ANNEX A

DESCRIPTION OF SIMULATORS AND DEVICES

1. A detailed description of most of the simulators visited during this evaluation is found in Appendices 1 through 11 of the annex. In addition, a description of most of the facilities/developmental devices that were discussed or observed by the evaluation team is included. The items emphasized are considered to be of interest to TAC for possible inclusion in future tactical fighter training devices.

2. In a few cases, the devices/facilities visited are not described in this annex. The Jaguar and air combat simulator were visited by the previous evaluation team, and a detailed description is included in the November 1977 final report. The demonstrations at General Electric Company in Daytona Beach, Florida, and at Singer-Link in Binghamton, New York, were more on the order of briefings, and there was very little hardware to describe. The radar scope interpretation trainer at RAF, Coningsby, is described adequately in paragraph 4 of this report.

APPENDIX 1

ANNEX A

CONTINENTAL AIRLINES DC-10 SIMULATOR,
LOS ANGELES, CALIFORNIA

1. GENERAL. The DC-10 flight simulator at Continental Airlines was built by the Singer Company, Link Division and accepted in October 1977. It is used to train pilot, co-pilot, and flight engineer crew members. The hardware configuration consists of the computer complex for the simulator and visual functions and a crew and instructor cockpit module on a six-DOF motion system.

2. COMPUTER COMPLEX. This complex consists of the following.

a. Flight Functions. These are controlled by dual Digital Equipment Corporation (DEC) 16-bit, PDP-11/45 computers. These minicomputers (CPU A7B) each have a 64,000 (64K) internal core memory and share a 16K metal oxide semiconductor (MOS) memory. Each computer is programmed in assembly language under DEC's RT-11 operating system.

b. Visual Functions. These are handled by a CPU-C and a DEC PDP-11/45 with a 32K core memory; of this memory, 4K is dedicated to input/output functions, and the remaining 28K memory is used by the operating system.

c. Peripherals.

(1) CPU-A and CPU-B utilize DEC RK 05-AA moving heads and removable disc/cartridge disc drives for mass storage of data. The single platter (disc) is capable of storing 25 million bits of information. Both object and source programs are stored on these removable cartridges. CPU-B has one drive, whereas CPU-A has two drives connected. With the second disc drive on line, CPU-A has a 20K memory dedicated to background functions. This permits simultaneous program modifications during normal system operation. A high-speed paper tape punch and reader setup is used to input or change the navigation aids stored in CPU-B.

(2) CPU-C uses a dual modified RX11 floppy disc to store the operating system (with DEC Com-10 compiler) software and up to six airport models. This floppy disc arrangement is capable of storing 256K bits of data. The airport models are initially put into the system on International Business Machine (IBM) punch cards via a DEC, 300-card-per-minute card reader. Communication with each central processing unit is via its own DEC WRITER II teleprinter (one per central processing unit) or via one of three VT-30 video terminals. Each of the VT-30 monitors (one in the computer complex and two in the cockpit) can monitor and change data in any of the aircraft parameter groups. A hard copy printout of the screen displays is provided by storing the data on discs and entering

the data into a 300-line-per-minute line printer (LP 11-VA, 132 columns, 64 characters).

(3) The computer complex contains one spare PDP-11/45 computer with DEC WRITER-II teleprinter and dual floppy disc. Diagnostics for the DEC equipment are on both paper tape and resident on discs. The data storage policy is a three disc set program, which includes the working set, the back up set, and the master set. This redundancy precludes total disasters from the loss of a recorded disc cartridge. Periodic updating of the backup and master disc set keeps the data current.

3. VISUAL SYSTEM. On the DC-10 this system is a Singer-Link NVS that employs a beam penetration CRT. It is used solely for night takeoffs and landings; consequently, only two windows were procured to provide frontal viewing. The windows employ 25-inch (diagonal) beam penetration tubes, which provide FOV of 48° horizontally and 36° vertically. The scene is coded in seven colors (yellow-white, orange, amber, gold, red, chartreuse, and green) and covers an area within a radius of 32 miles.

4. MOTION SYSTEM. The six-DOF motion system is built by Singer-Link and is capable of supporting 24,000 pounds on jacks with 60-inch travel.

CHARACTERISTICS

Movement Limits	Parameters
Pitch	36° up, 31° down
Roll	±32°
Yaw	±32°

Simultaneous movement limits (excursion envelope)

Vertical	±6 inches
Lateral	±6 inches
Longitudinal	±6 inches
Pitch	±4°
Roll	±4°
Yaw	±4°

Maximum velocity

Vertical	24 inches per second
Lateral	24 inches per second

Excursion from midtravel

Vertical	up 33°, down 38°
Lateral	±58°
Longitudinal	±53°
Pitch	up 36°, down 31°

Roll	±32 inches
Yaw	±32 inches

5. INSTRUCTIONAL FEATURES. The DC-10 simulator is capable of separating the engineer and instructor functions from the pilot/co-pilot and instructor functions; this permits independent and simultaneous crew position performance. The simulator is equipped for dual configuration operation; that is, two different DC-10 flight performance configurations (e.g., thrust, engine type) are programmed and available for any mission. A complete recording is incorporated that allows the instructor to replay up to 10 minutes of the previous flight. This replay actually flies the simulator "hands-off" while the student observes.

APPENDIX 2

ANNEX A

C-5A SIMULATOR, TRAVIS AFB, CALIFORNIA

1. GENERAL. The C-5 simulator was built by Conductron and delivered to Travis AFB during early 1970. The simulator hardware consists of a cockpit mounted on a three-DOF motion base and the computer complex with electronics, an operator's station external to the cockpit, and a visual system. The cockpit contains stations for the crew consisting of pilot, co-pilot, navigator, and engineer, along with positions for an IP, instructor navigator, and instructor flight engineer. Malfunctions entered by one instructor are displayed on video monitors for the other instructors' benefit. Malfunctions are entered at the IP station by knob selection of the fail number and then depressing an ENTER switch; deletion is by the same process but by depressing a DELETE button.

2. COMPUTER COMPLEX. The computer complex consists of the following equipment:

a. SEL 840A. This 24-bit computer with a 32K core memory, built by Systems Engineering Laboratories (SEL), performs the main flight/performance functions and also serves as the main computer.

b. SEL 840 MP. This 24-bit computer with a 40K core memory provides the navigation aids and radar land mass functions.

c. TI 980B. This 16-bit computer with a 16K MOS memory was built by Texas Instruments. It controls the video monitors in the cockpit and operates control loading functions.

d. TI Silent 700 Teleprinter. This communicates with the TI 989B computer.

e. ASR 33 Teletypewriter. This communicates with the SEL computers.

f. High-Speed Paper Tape Reader and Punch. This is used for loading bootstrap programs.

g. Magnetic Tape Drive. This is a 7-track drive built by Ampex and is used to load programs on the SEL computers.

3. VISUAL SYSTEM.

a. This is an add-on system built by Redifon/Evans and Sutherland and received in October 1977. It is an Evans and Sutherland Novoview SP-1. The computer is another TI 980B with a 48K MOS memory, 16 bits, coupled to a TI Silent 700 ASR teleprinter. A Tektronix 4010 graphics terminal

is used for graphics modeling and viewing. Airport models and operating programs are stored on dual floppy discs (6200 LP). The dual configuration permits airport modeling on the graphics terminal via background mode in software. Each disc drive is capable of storing 300K words of 16-bit data on one diskette. The drive has one head for record/read functions; this means the floppy disc must be stopped and the diskette turned over to read data (i.e., another airport model) recorded on the other side. Minor modifications to the dual drive setup could link the two and thus provide 600K words of data.

b. The viewing hardware consists of standard 25-inch beam penetration tubes providing an FOV of 48° horizontal and 36° vertical. Placement of the five windows (three for pilot, two for co-pilot) provides viewing for the pilot from 100° left of center to 20° right, for a total FOV of 120°. For the co-pilot, the two windows provide viewing from 20° left to 70° right, or approximately 90° total. Another window could be added to the co-pilot side if desired.

c. The system accommodates 6,000 light points plus 64 edges and displays five colors (red, orange, amber, yellow, and green). Edges can be increased to 256 (200 surfaces) by the addition of circuit boards common to the existing equipment.

d. The air refueling feature of the visual system employs a model KC-135 tanker that is flown by the simulator operator from the external console.

4. MOTION SYSTEM. The three-DOF motion system provides for pitch, roll, and yaw.

Movement Limits	Parameters
Roll	±11°
Pitch	±14°
Heave	±12°
Vertical acceleration	±0.8 G-force from 1 G-force
Vertical translation	±0 inch, +24 inches
Angular rotation, pitch	-6°, +14°
Angular rotation, roll	±9°

5. INSTRUCTIONAL FEATURES. A video recorder option can be used to record the visual display for replay. The equipment was not used at this site because discrepancies were corrected as they occurred and not stored for future discussion.

APPENDIX 3

ANNEX A

SINGER DRLMS, DIG AND NVS

During the visit to the Link Division of the Singer Company, Sunnyvale, California, the team was briefed and shown demonstrations on digital radar land mass system (DRLMS), digital image generation (DIG), and NVS.

a. DRLMS.

(1) F-14. The F-14 DRLMS incorporates 3 Raytheon RDS500 mini-computers, each with 32K, 16-bit core memories. One computer controls the transfer of data through the memories. A second RDS500 performs real-time operations, updates the antenna simulation function, and controls data movement through the real-time computational subsystems to the displays. A third central processing unit provides electronic countermeasures computations. All central processing units are used for diagnostic routines.

(a) Link DRLMS systems employ a memory hierarchy whose successive stages decrease in size but increase in speed. They are called regional memory, district memory, and sector memory. Regional memory of the F-14 DRLMS consists of an Ampex 3330-3 moving head disc capable of storing 200 megabytes of data. Regional memory contains the operating system, diagnostics, and 1250 by 1250 nautical miles (NM) of data at the 300- to 500-foot level. District memory contains data within radar viewing range of the aircraft and is continuously updated as the aircraft moves through the gaming area. The F-14 district memory uses the Intel 32-megabit, charge coupled device memory in place of the Pacific Micronetics 50-megabit, fixed-head, 8-bit parallel memories used in earlier F-4F and Project 1183 DRLMS systems. System peripherals include a Teletype Corp. ASR-35, a Pertec 9-track, 800-bit-per-inch (bpi) magnetic tape drive, and a paper tape reader.

(b) A notable capability, demonstrated earlier on the F-14 DRLMS, is the transformation of both Defense Mapping Agency DRLMS source data and Link-digitized data from T-10 factored transparencies producing DRLMS-compatible data and real-time DRLMS imagery.

(2) C-130. The C-130 DRLMS represents third generation Link DRLMS technology. The control computer subsystem is an Interdata 8/32 with 256 kilobytes of memory. Three 300-megabyte CDC 9760 moving head disc drives, coupled to a Diva controller, provide storage for operating and diagnostic software, 600,000 square NM of regional memory-stored data base at a 100-foot resolution, and 50,000 square NM of thunderstorm data base.

(a) District memory is Motorola random access memory and consists of 48 megabits of list structured data and 160 megabits of grid structured data.

(b) A significant improvement in the C-130 DRLMS relative to earlier DRLMS systems is the use of Intel static random access memory mounted on Link circuit cards, which function as sector memory. Previous designs use banks of core memory with many flat cables.

(c) The update subsystem includes a Tektronix 4014 terminal with hard copy unit and a graphics tablet. The tablet provides the capability to create thunderstorm data bases graphically. A Carousel 35 teletypewriter and 9-channel, 800-bpi magnetic tape drive make up the included peripherals.

b. DIG.

(1) The F-111 DIG. This is the current Link production day/night digital visual system. This visual system is controlled by an Interdata 8/32 minicomputer with 512 kilobytes of memory. The system uses a CDC 9760 80-megabyte moving head disc capable of storing 250,000 edges. Peripherals include a Tektronix 4010 CRT, 4631 hard copy unit, 4954 X-Y table, and a 9-channel, 800-bpi magnetic tape drive. The F-111 DIG provides an 8000-edge, full-color scene with up to 256 intersections per scanline, 256 priority levels, and such special features as variable visibility, moving targets, and weapon delivery effects.

(2) Laboratory DIG System. A demonstration was conducted on a laboratory model DIG system used by Link for data base experimentation. This system is first-generation hardware and does not have all of the capabilities of later systems. It provides 4,000-edge scenes with up to 256 intersections per scanline and 256 priority levels.

(3) Current DIG Research and Development. Visual simulation activities include the effects of shadowing, texturing, and circles and the addition of multiple illumination sources and other phenomena to the displays. Performance capabilities have improved from 8,000 edges at an update rate of 30 time per second to 12,000 edges at 30 times per second or 6,000 edges at 60 times per second. Intersections per raster line range from 256 to as many as 1,024 for various Link programs.

c. NVS. The F-16 system uses a DEC/PDP-11/35 computer with a 32K core memory. The system incorporates a dual floppy disc capable of 128 kilobytes of storage on each drive. One drive is dedicated to operating system functions; the other, to data storage. A documentation card reader is used to load visual data into the floppy disc via punched cards. The data base can be sized to 170 by 170 NM, with 13,000-15,000 lights and 3 active runways. The display provides a 48° by 36° FOV in a single window with a 25-inch CRT having infinity optics.

APPENDIX 4

ANNEX A

EVANS AND SUTHERLAND SP-1 AND SP-2 VISUAL SYSTEMS
SALT LAKE CITY, UTAH

The Novoview SP-1 and SP-2 visual systems were discussed at Evans and Sutherland and then demonstrated. With the exception of the display tube, most of the hardware is the same for both systems; hence, SP-1 will be discussed in detail and the differences from SP-2 will be noted.

a. SP-1.

(1) The computer is a TI 980B general purpose 16-bit computer with a 32K- to 65K-word MOS memory.

(2) The SP-1 is equipped with TI 733ASR data terminal with keyboard, thermo printer (30 characters per second/80 characters per line), and dual digital tape cassettes. This equipment communicates with the computer, provides hard copy print of data input/output, and provides tape storage of data. The tape cassettes are capable of storing 150K words per tape.

(3) The 6200 LP dual floppy disc by Advance Electronics Devices is used for mass storage of data and operating software. The drive uses IBM-type, dual-sided, soft-sectored diskettes, capable of 300K words storage per side. Single head configuration requires that the diskette (platter) be turned over to read/record the other side. The system can be expanded to two dual drives for a total of 1 megaword storage.

(4) Optional peripherals include CRT data terminals, hard copy/platter units, and line printers.

(5) The SP-1 has the following display features.

(a) The display portion uses a standard 25-inch beam penetration tube to provide a FOV of 48° horizontal and 36° vertical. The red/green phosphors supply the colors red, orange, amber, yellow/white, and green over 6,000 by 4,500 addressable points with a high brightness of 18-footlamberts white. This system can display 6,000 light points, 400 strings of 1 to 255 lights per string, curved strings, directional effects, traffic, stars, and special lights such as strobe, beacon, visual approach slope indicator, and high intensity runway lights. Also displayed are landing lights and weather simulation to include halo effects, glare, clouds, and fog.

(b) Multichannel operation can provide up to eight views with all scene elements in all views and no trade-offs between views. Modular assemblies permit ease of expansion and maintenance replacement.

(c) The use of data-base management techniques permits increased data-base sizes of 1300 by 1300 miles modeling domain, and a local operating envelope of 400 by 400 by 10 miles. This includes 128 edges/128 faces or 256 edges/200 surfaces.

(d) Although light point occulting is available as a feature, it was not incorporated in the system installed on the C-5A at Travis AFB. During display of the inflight refueling capability, wing lights could be seen through the tanker fuselage. Light point occulting was demonstrated at Evans and Sutherland.

b. SP-2. The primary difference between the SP-1 and SP-2 is the type of tube used for display of the visual scene. SP-2 uses a shadow mask, full-color CRT, which is driven calligraphically by an image generator with the features of SP-1 but with some modification. Addition of the blue-color component enables display of the complete color spectrum. An "anti-aliasing" process reduces or eliminates the effects of scintillation, crawling, and stair-stepping, which are most noticeable and distracting when the CRT brightness is increased on standard tubes. SP-1 systems can be easily upgraded to the SP-2 configuration.

APPENDIX 5

ANNEX A

SHUTTLE MISSION SIMULATOR,
NASA, JOHNSON SPACE CENTER,
HOUSTON, TEXAS

1. GENERAL. The shuttle mission simulator (SMS) is composed of two crew stations (modules) with visual systems. The motion base crew station is mounted on a six-DOF motion system and is limited to training at commander and pilot crew positions. The larger, fixed base crew station does not have the motion feature but includes capability for training at the orbiter aft crew positions (mission specialist, payload specialist, z-axis rendezvous, and remote mission system operator). The complete simulator, with the exception of the government-furnished Univac host computer, was developed by the Singer Company and delivered May through August of 1978 (see Figure 5-A-1).

2. COMPUTER SYSTEM. A Univac 1100 computing system with a large set of peripherals functions as the host or main computer for the simulator. This system performs most of the orbiter system simulations and modeling of the vehicle environment. Connected to the Univac system are two strings of interdata 8/32 computers (three per crew station) and their attendant peripherals. Each interdata computer performs as an intelligent controller to communicate with specific portions of SMS hardware. This hardware includes a full complement of equipment including shuttle flight computer, instructor/operator stations, crew stations, and visual displays.

3. VISUAL SYSTEM.

a. The two SMS crew stations presently have four of six forward windows activated by a visual system. The visual system includes a DIG as well as a shared camera/model system. The DIG system, built by Singer-Link, utilizes interdata 8/32 computers and is capable of 10,000 face boundaries of information for each crew station. The camera model system is shared by both crew stations as an alternate input source.

b. Each crew station has its individual subcontroller, DIG, visual effects generator, image processor and controller, visual system transmitter with a common camera model, and gantry/servo system. The model is an accurate, scaled, relief map of Edwards AFB, California. The model is a 56- by 24-foot representation of an area 19.8 by 8.5 NM. Each crew station may timeshare the camera inputs. Either DIG or camera scenes may be displayed through any four consecutive windows at either crew station, with the commander's and pilot's windows showing identical views, each 46° horizontal by 40° vertical, of the total scene.

c. Each window consists of a viewing head that comprises a 25° diagonal color CRT monitor, a spherical mirror, and beamsplitter. The CRT operates

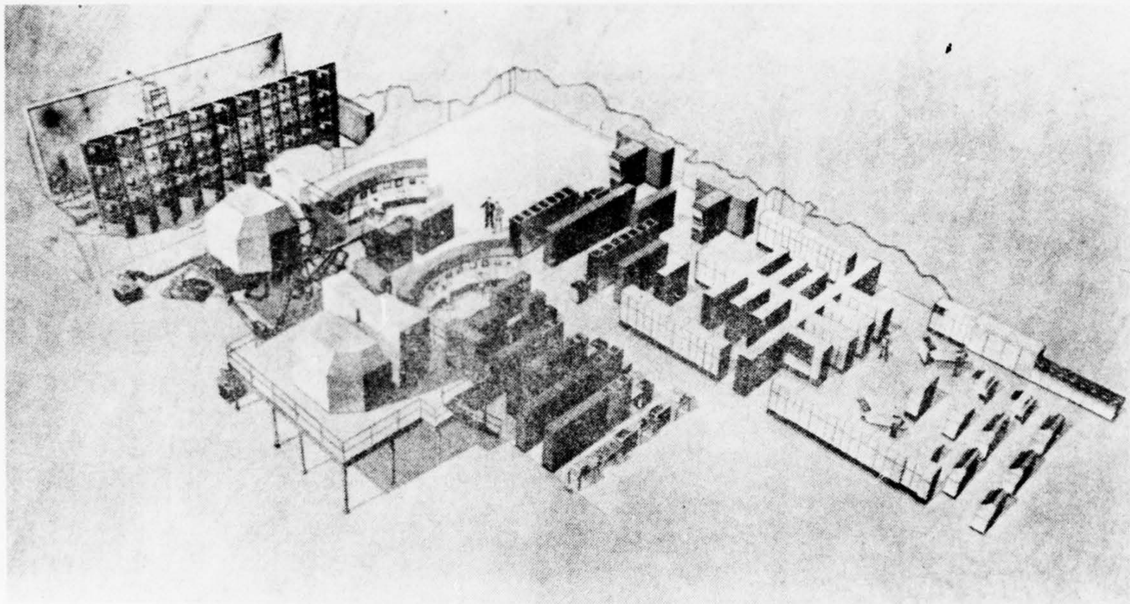


Figure 5-A-1. Shuttle Mission Simulator.

at 775 lines, interlaced 2:1, 30 frames per second with a 50-percent duty cycle to avoid camera lag and CRT linear deflection problems.

d. Future visual displays for the fixed base crew station will utilize a DIG for simulation of the payload by closed circuit television system. Views from seven cameras will be simulated. In addition, a fourth DIG system will generate out-the-window scenes for the aft and overhead windows of the crew station for use in payload specialist and mission specialist crew training.

4. MOTION SYSTEM. The motion base is a standard Singer-Link system with 54-inch stroke and six DOF. With an extended pitch feature, the pitch excursion is approximately 105°; from the horizontal, the total pitch excursion is from -24° to +105°.

Limitations (Normal)

Rotation	Excursion (degree)	Velocity (degree/second)	Acceleration ($degree/second^2$)	Onset Acceleration ($degree/second^2/second$)
Pitch	+26 -24	15	50	300
Roll	±18	12	50	300
Yaw	±12	11	50	300

Displacement	Excursion (inches)	Velocity (inches per second)	Acceleration (G-forces)	Onset Acceleration (G-forces per second)
Longitudinal	±42	24	0.5	±3
Lateral	±42	24	0.25	±3
Heave	±36	24	0.50	±4

5. INSTRUCTIONAL FEATURES. The instructor/operator stations are located external to the crew stations. These stations are equipped with CRT systems for display of crew station panels and simulate system status information. The CRT system also provides the input/output capability for simulated malfunctions to the shuttle onboard system simulations. Each operator station has two CRT keyboards with light pens, two communications keysets, and simulator status/readiness controls and indicators. Each instructor station has four CRT keyboards with light pens, four communications keysets (with dual headset capability), and dedicated repeaters of the crew station CRT displays. Each console has the capability to selectively monitor the crew station visual displays.

APPENDIX 6

ANNEX A

ADVANCED LOW-COST G-CUEING SYSTEM,
AIR FORCE HUMAN RESOURCES LABORATORY,
WRIGHT-PATTERSON AFB, OHIO

The advanced low-cost G-cueing system was developed by Singer-Link and delivered to the Human Resources Laboratory in late 1977. This advanced G-force cueing system is a closed-loop servo hybrid system utilizing hydraulic actuators to provide cushion surface elevation and orientation changes, and pneumatic firmness bladders to provide flesh pressure and area of contact variations. Conversion to hydraulics, from the previous all pneumatics for some functions, increased the response time by a factor of 10 with a 30-microsecond rise time. The hybrid approach reduces the number of seat actuators from 32 to 14.

a. G-Seat Sources. This is the most complex of the three cueing sources and consists of two major assemblies: the seat pan cushion and the backrest cushion. The combined motion of these two assemblies provides excursions in four DOF.

(1) The seat pan cushion assembly is mounted in the seat area normally occupied by the aircraft seat survival kit. The seat pan box measures 15 inches by 15 inches by 6 inches and contains six hydraulic actuators. Three actuators drive an upper plane in pitch, roll, and heave; two actuators drive the lap belt in the longitudinal and vertical axes and differentially in the lateral axis. The sixth actuator drives the top plane in fore and aft motion. Mounted on the top plane are the passive tuberosity blocks and thigh ramps covered by a dual cell firmness bladder. The thigh ramps contribute to an increase in flesh area of contact, whereas the tuberosity blocks provide an increase in localized buttock pressure, both occurring during deflation of the firmness bladder.

(2) The backrest assembly contains five actuators packaged in a volume 15 inches by 21 inches by 3 3/4 inches. Three actuators drive the top plane similar to the seat pan, while the other two drive the radial wings located in the lower corners of the top plane. The latter causes an increase in area of contact in the lower back region as the wings are extended. Mounted on the top plane is a single cell firmness bladder.

b. G-Suit System.

(1) The G-suit system employs an unmodified G-suit with the internal pressure regulated as a function of simulated aircraft acceleration. The addition of a vacuum, assisted by a booster valve, improves G-suit pressurization and exhaust rates.

(2) The seat shaker consists of a short body hydraulic actuator mounted to the rear of the seat frame. The system provides vibration and buffet cues of a sinusoidally continuous and/or discrete form for use in replicating such events as stall-buffet, background rumble, and speed brake buffet.

c. System Performance Characteristics.

Component	Axis	Excursion	Response
Seat pan	Roll, pitch	+12°	30 microseconds, 10 hertz
	Heave	±1.25 inches	
	Fore-aft	±1.0 inch	
Backrest	Pitch	±6°	30 microseconds, 10 hertz
	Yaw	±9°	
	Surge	±1.25 inches	
Seat	Roll	¯1 inch	30 microseconds, 10 hertz
Backrest	Heave		
Bladders	Surge		
Seat shaker	Heave	+0.25 inch	34 hertz
Lap belt	Fore-aft	±1.5 inches	30 microseconds, 10 hertz

APPENDIX 7

ANNEX A

AVIATION WIDE ANGLE VISUAL SYSTEM,
NAVAL TRAINING EQUIPMENT CENTER,
ORLANDO, FLORIDA

1. GENERAL. The conventional takeoff and landing simulator previewed at the Naval Training Equipment Center consists of a visual system, a six-DOF synergistic motion base, a cockpit, G-seat, computer complex, and experimenter's console (see Figure 7-A-1). The flight simulator is configured as a US Navy T-2C aircraft with complete aircraft systems operation. Simulator maneuvers include carrier simulation (pitch, roll, heave, sea state, wind, wind gusts, air burble, etc.), arrested landing and catapult takeoff, rough air, and aural simulation. Carrier and aircraft positions are resolvable to 1/8 foot.

2. COMPUTER SYSTEM. The computer complex consists of dual SEL 32/55 computers, main memory, and a common core memory to be used for data transfer between the flight, visual, and performance assessment systems. Major programs are in FORTRAN language with 30-time-per-second iteration rates for visual, aeronautical performance, and motion as required. One SEL computer with CRT terminal and 3- by 32-kilobyte memory is dedicated to control of the visual system. The other SEL computer with 8- by 32-kilobyte memory performs all of the flight performance and motion control computations. The complement of peripherals include two 10-megabyte disc drives, two magnetic tape units, CRT terminal, card reader, line printer hard copy unit, and graphic CRTs. One 32-kilobyte memory is shared by the two SEL computers.

3. VISUAL SYSTEM. The visual display is a monochrome, wide-angle real image presented on a 10-foot-radius spherical screen. The entire display system, consisting of screen, two television projectors, and a Fresnel lens optical landing system (FLOLS) projector, is mounted on the motion base. The target image can be positioned anywhere within the screen FOV of +90° to -30° vertical and ±120° horizontal. The target projector presents the carrier image, which can be superimposed upon a background seascape image or inset into it. A full-color FLOLS is optically combined with the target projection optics to provide a very high resolution and bright FLOLS display for long range visibility, in order to match performance with the real-world system. The 160° background seascape display can be centered on the aircraft axis or offset 40° to the left.

a. The image generation equipment includes both model and film sources. The carrier is a 370:1 scale model of the Forrestal (CVA-59) viewed by a television camera through an optical probe with a 4:1 zoom capability. The camera is mounted on a 22- by 22-foot servoed gantry, which is able to simulate up to 400 knots air speed at this scale factor. The seascape is generated from a photographic film plate scanned by a CRT flying spot

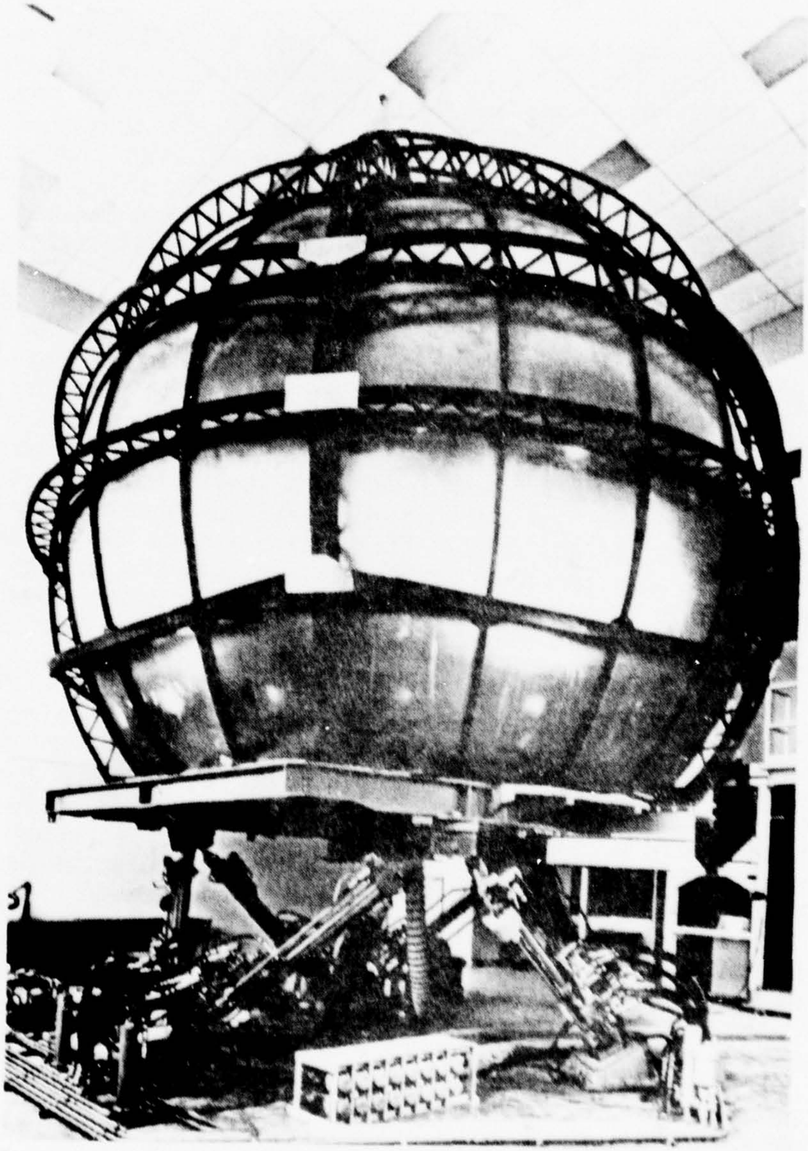


Figure 7-A-1. US Navy Aviation Wide Angle Visual System.

scanner. Full visual cues are generated from 760 feet down to carrier deck height. Above 760 feet, a cloud layer is introduced through the special effects subsystem, which also produces cloud top and bottom with scud for breakout effects.

b. The real-time computer image generation system, utilizing a DEC PDP-11/55 with a 32K core memory and two RD05 disc units for mass storage, is capable of storing a 200- by 200-NM gaming area, consisting of 10,000 edges on-line with dynamic update from mass storage disc and 2,000 light points. The peripheral equipment includes a 9-track magnetic tape unit, line printer (300 lines per minute, 132 columns) and DEC WRITER II terminal.

(1) This sytem generates black and white continuous tone television outputs which are expandable to color. It has selectable line rates of 525, 825, or 1,023 and can provide a picture capacity of 2,000 edges at either a 60- or 30-time-per-second update in single or dual channel operation. Antirastering (edge smoothing), curved surface shading, and six moving targets can be provided.

(2) Complete demonstration of the visual capabilities of the aviation wide angle visual system was not possible during this visit because of data transfer and computer integration problems. Fluctuation of the minor order bits of the aircraft position data words was detected by the computer image generation computer as aircraft movement which caused the generation display to jump excessively.

4. MOTION SYSTEM.

a. The motion platform is a synergistic six-DOF system instrumented to record actual position and acceleration in each DOF.

Limitations (Normal)

Rotation	Excursion (degree)	Peak Acceleration (degree/second^2)	Peak Velocity (degree/second)
Pitch	+24 -26	±145	±15
Roll	+22	+230	+15
Yaw	±29	±230	±15

Displacement	Excursion (inches)	Peak Acceleration (G-forces)	Peak Velocity (inches/second)
Vertical	+24	+0.8	+24
Lateral	±42	±0.8	±24
Longitudinal	±48	±0.8	±24

b. The G-seat is similar to first-generation G-seat designs (KRON, 1975) with improvements incorporated in thigh panel reliability and bellows element retraction rate. This all-pneumatic system has 30 elements in the seat pan and back panel synchronized to function with or without the motion platform to provide simulation of acceleration vectors.

5. INSTRUCTIONAL FEATURES. The experimenter/operator station provides the capability to interact with the computer and flight simulator for the purpose of developing, controlling, monitoring, and recording. The station is a three-rack turret console with four computer-driven CRT displays, one video CRT display, one hard-copy unit, one keyboard, one "joy stick," and switches.

APPENDIX 8

ANNEX A

DIFFERENTIAL MANEUVERING SIMULATOR,
NASA, LANGLEY AFB, HAMPTON, VIRGINIA

This simulator was visited during the initial evaluation and was described in the November 1977 Simulator Comparative Evaluation Final Report. However, since that evaluation, a helmet loader G-cueing device and a G-seat have been added to the system. This description will be limited to a discussion of these two add-on features.

a. Helmet Loader G-Cueing Device (HLD).

(1) In high performance aircraft the G-forces on the pilot's helmet provide important feedback concerning the aircraft's dynamic state as well as limit the pilot's ability for head movement when the G-forces are high. This HLD provides the proper cues without restricting the pilot's movement or requiring cumbersome attachments. The loader follows the pilot's movement while providing the proper forces and requires only two small strings to be snapped on the helmet.

(2) The HLD is designed to use force feedback in order to follow the pilot's movements while providing proper helmet forces. Two small pulleys are attached to the pilot's shoulder straps (see Figure 8-A-1). The strings from the torque motor pass through these pulleys and up to the helmet where they apply a downward force to simulate G-force application. The excess cable between the helmet and the force transducer allows for unrestricted turning of the head; a torque motor has sufficient cable wound on its reel to allow for all body and head movements of the pilot.

(3) The HLD is essentially a 0.4 damped second order system with a 20-millisecond steady state time delay. It has been scaled at approximately 2/3 the inflight helmet loads. It exerts 40 newtons (9 pounds) of force at the selected full scale command of 6 G-forces. The HLD uses breakaway straps on the helmet, current and voltage limits, and small torque motors to insure that the pilot does not experience excessive forces.

b. G-Seat.

(1) A seat cushion to provide acceleration cues to aircraft simulator pilots was installed in the DMS in 1977. The four-cell seat, by using a thin air cushion with highly responsive pressure control, attempts to reproduce the same events that occur in the aircraft seat under acceleration loading. In order to compress the seat padding as if the pilot weighed more, air with pressure control is used as the padding material with a non-compressible surface (wood) underneath the air cushion.

Figure 8-A-1. Helmet Loader NASA Langley Research Center.

(2) The seat is initially biased so that the air conforms to the pilot to support most of his weight. The initial air pressure allows the two main support areas, the tuberosities, to touch the wood surface and begin to compress the flesh near these areas. Thus the bias adjusts the firmness of the seat. As accelerations increase (positive G-forces) air is removed from the seat; this gives the effect of compressing the cushion material and causes more of the pilot's weight to be supported by the area around the tuberosites. This manner of seat operation (reproducing the aircraft seat actions) automatically reproduces other related pilot events of raising or lowering the body, which results in changing the eye point and the joint (hip and knee) angles.

(3) The air cushion is made of pliable rubber and has four air cells per seat plus a back cushion with individual pressure controllers for each of its eight cells. The air cushions are 2.54 centimeters thick to minimize "following" as the pilot's weight is shifted and to increase response time by lowering the air volume required. The inherent design of the seat requires precise and responsive control of the air pressure in each cell. The system is essentially a 0.45 damped, 25-radian-per-second, second order system over the range of 0 to 8 hertz. This provides a 56-millisecond time lag from seat command to seat pressure over the full range of operation of the seat.

APPENDIX 9

ANNEX A

DEUTSCHE LUFTHANSA B707/330C, FRANKFURT, GERMANY

1. GENERAL. This simulator is a Boeing 707/330C built by Redifon Simulation Incorporated in 1971. The equipment consists of a cockpit with a 6-DOF suspended motion base and was originally equipped with two terrain model boards and a flat screen visual system. This was subsequently retrofitted with the Redifon duoview display visual system, which in turn was retrofitted with the Redifon Daynite CGI and monoview display system.
2

2. COMPUTER SYSTEM. This system for the simulator is in another room and consists of a Redifon 2000 computer with a 56K, 24-bit core memory, high-speed paper tape reader for initial loading of programs to disc storage and loading diagnostics, and the disc drive.

3. VISUAL SYSTEM. The visual system was supplied by Redifon/Evans and Sutherland and delivered in 1977. This system is a continuous tone-4 day, night, and dusk, two-window system, each window providing a FOV of 36° vertical and 48° horizontal. The two windows provide identical full-color displays for the pilot and co-pilot positions. This particular system operates as two independent channels serving two separate simulators with a 50-hertz update rate, and less than 75-microsecond through out delay. Two thousand polygons are stored on the disc; 400 polygons are in the pipeline process, with 200 polygons displayed on each channel of the 625 line raster CRT. The display can handle 2,000 lights per channel and 50 special lights per channel. The computer hardware is a PDP-11/45 with an RK05 DEC pack, and a DEC WRITER II teleprinter. Greater emphasis has been placed on image quality in this system than on quantity of information. Erasing techniques have been used that provide a clean picture, free from most of the unpleasant effects normally associated with raster scan CGI systems.

4. MOTION SYSTEM.

a. General. The motion system is a 6-DOF suspension system. The cockpit is supported by three hydraulic jacks plus three cross safety jacks from an overhead framework which connects to surge and lateral jacks to provide surge, yaw, and sideslip cues.

b. Performance.

(1) The six DOF provided by the motion system at the pilot's station are as follows:

Pitch
Heave or vertical translation
Roll

Sway or lateral translation
Surge or fore and aft translation
Yaw

(2) The usable excursions in these axes at the pilot position, including actuator cushioning zones, are as follows:

Pitch ±28°*
(All other axes in mean position.)

Heave ±1.219 meters (48 inches)
(All other axes in mean position.)

Roll ±19°
(All other axes in mean position.)

Sway ±1.829 meters (72 inches)
(All other axes in mean position except yaw. Yaw is to starboard at the starboard extremity of sway and to port at the port extremity of sway).

Surge ±876 millimeters (34.5 inches)
(All other axes in mean position).

Yaw ±13°
(All other axes in mean position except sway actuator driven to keep sway to a minimum).

*With the pilot stations between the forward two heave jacks the ±28° of pitch is accompanied by ±1.219 meters (48 inches) of heave.

(3) The velocities of the separate axes are as follows:

Pitch	±17°/second
Heave	±762 millimeters/second
Roll	±12°/second
Sway	±762 millimeters/second
Surge	±762 millimeters/second
Yaw	±11°/second

(4) The accelerations of the separate axes are as follows:

Pitch	±80°/second^2
Heave	±3/4 G-forces
Roll	±80°/second^2
Sway	±1/4 G-forces
Surge	±1/2 G-forces
Yaw	±80°/second^2

(5) The motion system is capable of sustaining for 22 seconds a maximum demand equivalent to a sustained Dutch roll on the simulated aircraft. This has been assumed to be a sinusoidal motion in roll and sway of a 4-second period having peak velocities in roll and sway of 12°/second and 762 millimeters/second (30 inches/second), respectively.

(6) The motion system is capable of satisfying for 15 seconds a maximum short term demand equivalent to engine failure at rotation in which the wrong corrective action is taken. This has been based on a sinusoidal sway motion of not more than a 9-second duration and peak velocity of 762 millimeters/second, coupled with random roll/pitch/heave motion in which all the vertical jacks perform sinusoidal motion of not more than 9 seconds with period and peak velocities of 12°/second, 17°/second, and 762 millimeters/second, respectively.

APPENDIX 10

ANNEX A

CONTROL LOADING SYSTEM AND SCANNED LASER VISUAL SYSTEM, REDIFON SIMULATION LIMITED, CRAWLEY, UNITED KINGDOM

1. CONTROL LOADING SYSTEM.

a. The simulation of the control loading (feel) is such that the control forces experienced by the pilot under all flight conditions are realistically reproduced.

b. The primary flying controls are loaded by a highly responsive advanced electrohydraulic servo system, using very low friction hydrostatic jacks and force servo techniques. The design of the system provides a high degree of flexibility; this enables changes of characteristics that result from aircraft modifications to be easily incorporated. The elevator, rudder, and aileron load effects are computed independently, but the computing technique for all these channels is similar. All flying controls on the flight deck are aircraft units and will incorporate the normal adjustments as in the aircraft. Rudder and aileron trim are operative with autopilot input provided to the stabilizer trim system.

c. Modular force servo systems are used to generate the control loads applied by the hydrostatic force jacks. The servo systems respond to aerodynamic and aircraft system inputs from the digital computer along with force and position inputs from a load cell and position transducer. The hydrostatic force jack has friction levels typically 80 percent lower than earlier systems. As a result, the response of the primary servo loop has been increased by a factor of 10 with bandwidths demonstrated in excess of 80 hertz. The primary servo loop is inherently stable and can be set up independently from aircraft characteristic input. Aircraft characteristics included in the simulation are as follows:

Viscosity
Inertia
Velocity limits
Backlash (dead band)
Cable stretch
Coulomb friction
Static friction
Breakout
Spring rate

Each of these characteristics can be independently adjusted throughout the aircraft range without affecting the stability of the overall system. In addition, steady state calibration is unaffected by adjustments to transient characteristics (e.g., viscosity and inertia).

d. Control loading system maintenance has been significantly simplified by the introduction of the inherently stable primary servo loops. The actuator units can be readily removed from the control loading frame for bench testing. The electronics associated with the load cell scaling and buffering, mechanical advantage correction, and column weight correction are mounted close to the relevant jack within the control loading frame. Each primary servo loop can be set independently for optimum linearity and performance prior to introducing inputs relating to the aircraft parameters.

2. SCANNED LASER VISUAL SYSTEM. This system is a research and development program and is still in its infancy. When evaluated at Redifon, the system had been switched on for only a month and displayed only a portion of its capability (see Figure 10-A-1). The technical and marketing development is proceeding cautiously, and no specific data may be published until a role has been identified and it has been associated with a particular mission program. Additional information can be obtained from the Scanned Laser Visual System Feasibility Study, contract number N61339-76-C-0018, 23 May 1976, prepared by A.M. Spooner, Chief Scientist, Redifon Simulation Limited.

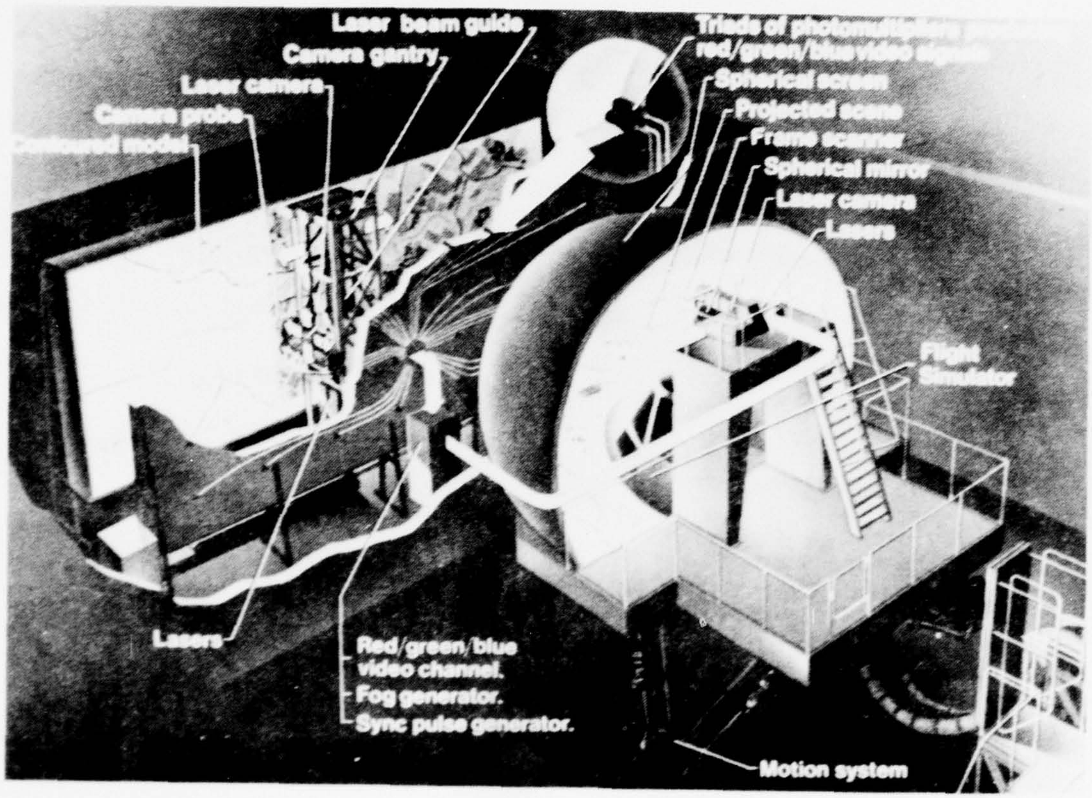


Figure 10-A-1. Scanned Laser Visual Depiction.

APPENDIX 11

ANNEX A

HAWK SIMULATOR, RAF VALLEY, UNITED KINGDOM

1. GENERAL. The five Hawk simulators, built by Redifon Simulation Limited, were delivered between December 1976 and February 1978 and consist of three-piece transportable containerized units (see Figure 11-A-1). The three pieces are fitted together (two end to end and one on top) to house the cockpit, computer, instructor console, peripherals, and power and linkage. The Hawk simulator is not equipped with a visual system; the original proposal called for a CGI novoview visual system, but a cost-effective decision resulted in its deletion.

2. COMPUTER SYSTEM. The simulator is controlled by a Redifon R2000A computer with a 32K, 24-bit core memory. Coupled to the computer for mass storage are two Diable Series 30 magnetic cartridge discs, capable of storing 24 megabits of data. One disc is used for storing the real-time programs, and the second disc is for storing 7 minutes of flight performance. Communication with the computer is via a Data Dynamics ASR 390 teletype with paper tape option. Other peripherals include a high-speed paper tape reader (TREND model HSR 500P) for loading paper tape programs and a paper tape punch teletype model BRPE1110 for punching program modules. All software, both diagnostic and operating system, is delivered on paper tape. The operating system is loaded on a disc for ready access each day. Diagnostic tests for each area under test are loaded from paper tape.

3. VISUAL SYSTEM. This simulator has no visual system.

4. MOTION SYSTEM.

a. The three-DOF motion system is designed to provide cues for acceleration, buffeting (slats, speed brakes), stalls, landing gear, and runway rumble.

b. The capabilities are as follows:

Heave	$\pm$12 inches from midtravel
Pitch	$\pm$15° up, -10° down
Roll	$\pm$10° from midtravel

5. INSTRUCTIONAL FEATURES.

a. The instructor station is equipped with two CRTs, keyboard and switches, 4-channel recorder, position plotting board, and line printer. The 20-inch diagonal CRTs are BARCO-type, color-displaying computer terminals capable of displaying 625 lines per picture interlaced at 50 fields per second. The CRTs display all data of interest to the

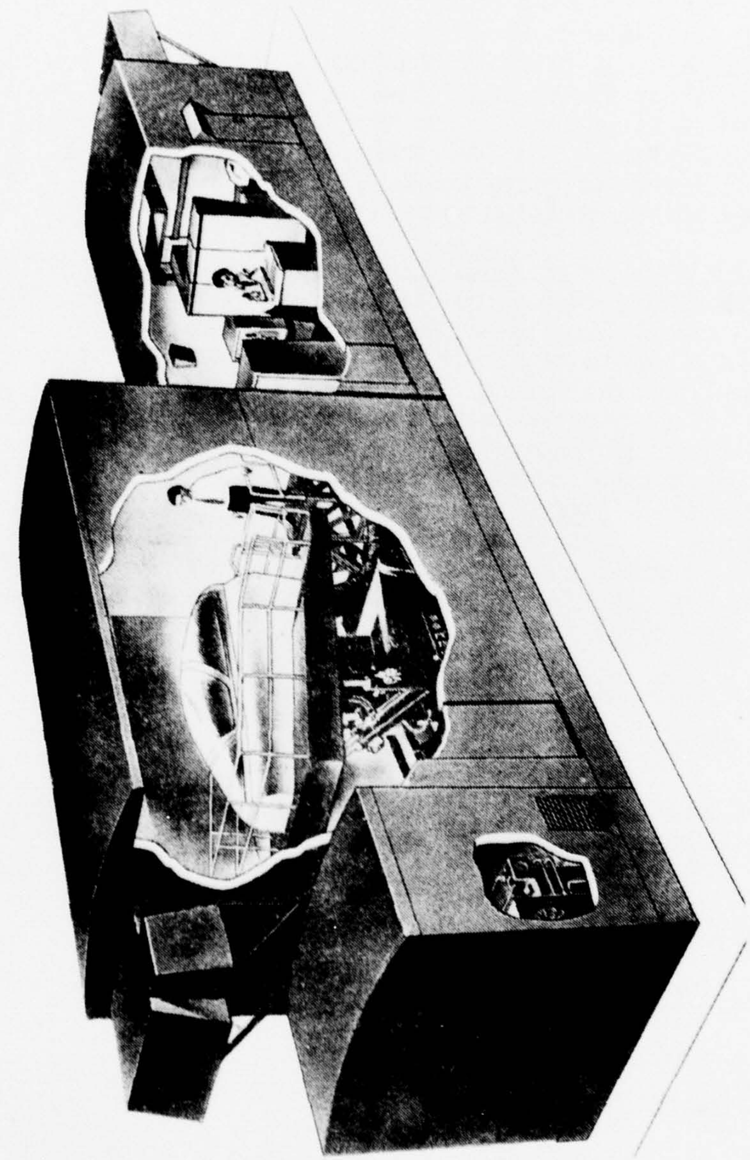


Figure 11-A-1. Hawk Simulator.

instructor to include aircraft performance/flight parameters, fault (malfunction) status and insertion/deletion, switch position activity by student, and diagnostic verification.

b. Interface between the computer and CRTs is by an MRCD 483 display generator with full-page memory. This unit provides all data on a color display at 80 characters/line and 50 hertz refresh rates. Coupled to the system is a CENTRONICS 101AL line printer, which provides a hard copy record of the CRT displays, switch activity, and approach parameter data.

c. A radio telephone chatter system by Television Research (type TR 404R) adds voice communication of a previously recorded sortie to the intercommunication system. A previous mission sortie is recorded on 4-track cartridge for replay during the current sortie. Also mounted on the instructor console is a 4-12 channel chart recorder built by Phillips Elektronikindustries AB. The multipoint recorder (PM 8235) is a single pen, 4-channel (expandable to 12) recorder, used to record approach and landing parameters (airspeed, range to touchdown, glideslope deviation, and localizer deviation). The 7-minute disc referred to in paragraph 2 permits 7 minutes of a training flight to be recorded and can be replayed for the student.

d. Faults (malfunctions) can be preprogrammed to occur at specific parameters such as altitude, and airspeed or time into flight. Two (or more) parameters can be specified, and the malfunction will occur when the first parameter is reached. Deletion of malfunctions can be by master clear (all malfunctions), page clear (all of a system, e.g., fuel), or individually.

DISTRIBUTION LIST

HQ USAF Wash DC 20330	
LEYY	1
RDPNR	1
RDQRT	1
XOOD	1
XOOFB	1
XOOTT	1
JQ AFHRL Brooks AFB TX 78235	
DO	1
XR	1
AFHRL/AS Wright-Patterson AFB OH 45433	1
AFHRL/ASM/Mr. Don Gum Wright-Patterson AFB OH 45433	1
AFHRL/FT Williams AFB AZ 85224	2
AFHRL/FTO Luke AFB AZ 85301	1
HQ AFLC Wright-Patterson AFB OH 45433	
AC	1
MMC	1
MMW	1
HQ AFTEC/TE Kirtland AFB NM 87115	2
HQ PACAF/DOO Hickam AFB HI 96853	1
HQ TAC Langley AFB VA 23665	
ACB	1
DO	1
DOO	3
DOX	1
DR	1
DRF	3
DRL	1
HO	1
LG	3
LGM	1
XP	1
HQ USAFE/DOO APO New York 09012	1
9 AF Shaw AFB SC 29152	
DOO	1
LGM	1
12 AF Bergstrom AFB TX 78743	
DOST	1
LGMA	1
ASD Wright-Patterson AFB OH 45433	
3D4E-3	1
ENECC	1
SD24	1
SMS	1
TACSO-A	1
USAFTAWC Eglin AFB FL 32542	
HO	2
OA	1
SE	1
TN	1
TNA	1
TNS	1
TNT	1
TX	1
USAFTAWC/OLAE Wright-Patterson AFB OH 45433	1
USAFTFWC Nellis AFB NV 89191	
SA	1
TA	1
TE	1
35 TFW/TT George AFB CA 92392	1
58 TTW Luke AFB AZ 85309	
DO	1
DOTI	1
MA	1
MAPS	1
MAADTA	1

60th Mil Airlift GP 1
Maj Alvin Machtmes
Travis AFB CA 94535

4444 OPS SQ/CC 3
Luke AFB AZ 85301

AFFDL/FG/Mr Anderson 1
Wright-Patterson AFB OH 45433

OO-ALC
Hill AFB UT 84406
MMR 1
MMS 1

Defense Documentation Center 2
Cameron Station
Alexandria VA 22314

AUL
Maxwell AFB AL 36112
DA 1
LSC 1

AFATL
Eglin AFB FL 32542
DL 1
ODL 1

US Embassy 2
HQ USDAO/AIRA
FPO New York 09510

NASA 1
Ames Rsch Ctr/Mr J.C. Dustberry
Moffett Field CA 94035

NASA 1
Ames Research Center
Mr. David Nagel
Moffett Field CA 94035

NASA 1
JSC/Mr. C.H. Woodling
Mail Code FE
Houston TX 77058

NASA 1
Langley Rsch Ctr/Mr. B.R Ashworth
Mail Stop 125B
Hampton VA 23665

ASW Wings, Pacific 1
Commander
Naval Air Station North Island
San Diego CA 92135

Chief of Naval Education
& Training 1
ACOS for Flight Training -N 4-
Naval Air Station
Pensacola FL 32508

Chief of Naval Air Training 1
ACOS Plans & Programs -N 2-
Naval Air Station
Corpus Christi TX 78419

Chief of Naval Air Training 1
Naval Air Station
Corpus Christi TX 78419

Chief of Naval Education and
Training Liaison Office 1
Air Force Human Resource
Laboratory
Flying Training Division
Williams AFB AZ 85224

COMMATVAQWING, Pacific 1
Naval Air Station
Oak Harbor WA 98278

COMFITAEWWING, Pacific 1
NAS Miramar
San Diego CA 92145

FASOTRAGRULANT 1
Commander Officer
Naval Air Station
Norfolk VA 23511

FASOTRAGRUPAC
Commanding Officer 1
Naval Air Station, North Island
San Diego CA 92135

Naval Air Development Center 1
Librarian
Warminster PA 18974

Naval Training Equipment Center 1
Librarian
Orlando FL 32813

Light Attack Wing One 1
Commander
Naval Air Station Cecil Field
Jacksonville FL 32215

Light Attack Wing One, Pacific 1
Commander
Naval Air Station
Lemoore CA 93245

Marine Air Weapon Tactics SQ 1
Commanding Officer
Marine Corps Air Station
Yuma AZ 85364

3rd Marine Aircraft Wing FMFPAC 1
Marine Combat Crew Readiness
Training Group Ten
MCAS Yuma AZ 85364

Naval Air Development Center 1
Commanding Officer
Warminster PA 18974

Naval Air Forces, Atlantic 1
Commander
Naval Air Station -Attn. Code-
Norfolk VA 23511

Naval Air Forces, Pacific 1
Commander
Naval Air Station, North Island
-Attn. Code-31
San Diego CA 92135

Naval Air Systems Command 1
Equipment & Support/Human Factors
Air 340 F-
Washington DC 23061

Naval Air Systems Command 1
AIR 413
Director, Weapons Training Div
Washington DC 23061

Naval Air Test Center 1
Director, USNTPS
Patuxent River MD 20670

Naval Education & Training 1
Support Center, Atlantic
Commanding Officer
Naval Air Station Bldg 286
Norfolk VA 23511

Naval Education & Training 1
Support Center, Pacific
Commanding Officer
San Diego CA 92132

Naval Training Equipment Center 1
Research & Technology Dept. -N 7-
Orlando FL 32813

Naval Training Equipment Center 1
Commanding Officer
Orlando FL 32813

Naval Training Equipment Center 1
Director, Training Analysis &
Evaluation Group
Orlando FL 32813

Naval Training Equipment Center 1
Engineering Dept. -N 22-
Orlando FL 32813

Navy Fighter Weapons School 1
Commanding Officer
Naval Air Station Miramar
San Diego CA 92145

Office of the CNO -OP 59- 1
Director, Aviation Manpower
& Training
Washington DC 20350

Patrol Wings, Pacific 1
Commander
NAS Moffett Field CA 94035

Patrol Wings, Atlantic 1
Commander
Naval Air Station
Brunswick ME 04011

Patrol Squadron 31 1
Commanding Officer
Naval Air Station
Moffett Field CA 94035

Patrol Squadron 30 1
Commanding Officer
Naval Air Station
Jacksonville Fl 32212

Sea Based ASW Wing, Atlantic 1
Commander
NAS, Box 102
Jacksonville FL 32212

Strike Aircraft Test Directory 1
Naval Air Test Center
NAS Patuxent River MD 20670

Tactical Wings Atlantic 1
Commander
Naval Air Station Oceana
Virginia Beach VA 23460

US Coast Guard ATC 1
Attn: Mr King Povenmire
Mobile AL 36608

HQ USMC 1
Training Device Office
Code APW
Washington DC 20380

Naval Training Equipment 1
Center
Mr Walter S. Chambers
Code N-741
Orlando FL 32813

American Airlines Plaza 1
Mr Gerald Wynn
Ft Worth TX 76101

BAC 1
Flt Sim Dept/Mr Arthur G. Barnes
Mil Acft Div/Warton
Lancastershire UK

Continental Airlines 1
Mr William Laughlin
7300 World Way West T-115
Los Angeles CA 90808

DDTO (RAF) 1
Group Capt D.M. Richard
Rm 219 Adastral House
Theobolds Rd
London UK WC1

Evans and Sutherland Corp 1
Mr Gus Liapis
580 Arapeen Dr
Salt Lake City UT 84108

General Electric GS Div 1
Mr Dallas Butler
Daytona Beach FL 32015

RAF Coltishall 1
Sqdn Ldr Richard Dye
NR Norwich UK

RAF Coningsby 1
OC 1 Sq/Sqdn Ldr R.J. Rodgers
Lincolnshire UK LN44SY

RAF Valley 1
Sqdn Ldr Alan Scott
Hollyhead Anglesey UK

Redifon Electronics, Inc 1
Mr Roy Molyneux
2201 Arlington Downs Rd
Arlington TX 76011

Redifon Flt Sim, Ltd 1
Mr Adrian Tripp
Gatwick Rd, Crawley
Sussex UK

Redifon Flt Sim, Ltd Mr John Bastow Gatwick Rd, Crawley Sussex UK	1
Science 3 (RAF) Mr A.G. Parfitt Rm 801A, Lacon House Theobolds Rd London UK WC1X8RY	1
Singer Co Link Div Mr Raymond J. Pawlikowski Binghamton NY 13902	1
Singer Sim Products Div Mr James O'Connell 1077 E. Arques Ave Sunnyvale CA	
Sperry Simulator Systems Mr R.E. Clapp 2724 Dorr Av Fairfax VA 22030	1

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
TAC Project Unnumbered

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
6 Follow-on Simulator Comparative Evaluation.

5. TYPE OF REPORT & PERIOD COVERED
9 Final Rep[redacted]t
23 Aug - 3 Oct 78,

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
10 Daniel L. Konopatzke Maj, USAF
Riker S. Van Arsdall Operations analyst

8. CONTRACT OR GRANT NUMBER(s)
12 67p.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
USAFTAWC/TNS
Eglin AFB FL 32542

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS

12. REPORT DATE
11 May [redacted]79

13. NUMBER OF PAGES

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Simulator
Aircrew Training Devices

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
The purpose of the follow-on simulator comparative evaluation was to evaluate those devices/developments which have occured in the simulator field since the original simulator comparative evaluation report, ~~Defense Documentation Center~~ number ADB023450L, ~~dated November 1977~~. The conclusions/recommendations reached in the current evaluation are intended to update those found in the first evaluation and to reflect state-of-the-art capabilities in simulation.

340 610

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)